MOSAIC

VOLUME 5, NUMBER 2, SPRING 1974

NATIONAL SCIENCE FOUNDATION

H. E. Carter, *Chairman*
National Science Board

H. Guyford Stever, *Director*
National Science Foundation

Theodore W. Wirths
Government and Public Programs
Director

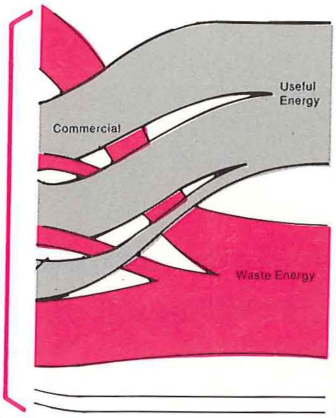
Editor: Bruce Abell

Staff: Barbara Tufty
Martha Jane Sordo Wilson

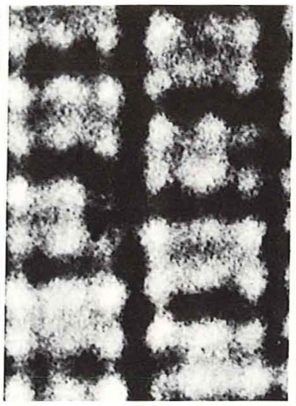
Mosaic is published four times yearly as a source of information for the scientific and educational communities served by the National Science Foundation. The Director of the National Science Foundation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this agency. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1976. Subscription is $4.50 per year in the U.S. and Canada and $5.75 foreign. Single copies are $1.25. Send check or money order to the Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 20402. Communications other than those concerning paid subscriptions should be addressed to: Editor, *Mosaic*, National Science Foundation, Washington, D. C. 20550. Telephone: 202 632-7390.

Photo Credits: Cover—Charles O'Rear/EPA Documerica; 8—Sumio Iijima/Arizona State University; 11—NOAA; 12—Bill Gillette/EPA Documerica; 13 (left)—Marc St. Gil/EPA Documerica; 13 (right)—Dan McCoy/EPA Documerica; 14—McDonnell-Douglas Corp.; 16—Aircraft Armaments, Inc.; 17—Honeywell, Inc.; 19—Gary E. Miller/EPA Documerica; 24—Pacific Gas and Electric Company; 26—Bureau of Reclamation/U.S. Department of Interior; 30—U.S. Patent Office; 32—Arthur Greenberg/EPA Documerica; 33—Robert Eustis/Stanford University; 37—Van Daniels/EPA Documerica; others—NSF.

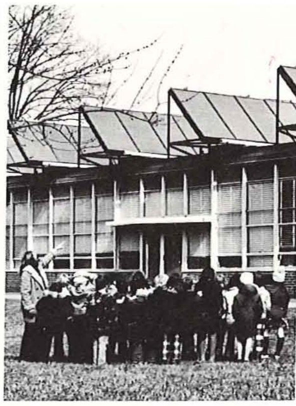
Cover: Electric transmission lines near Searchlight, Nevada. This issue of *Mosaic* examines the wide range of NSF's energy research programs.



2



8



16

Energy For America's Third Century

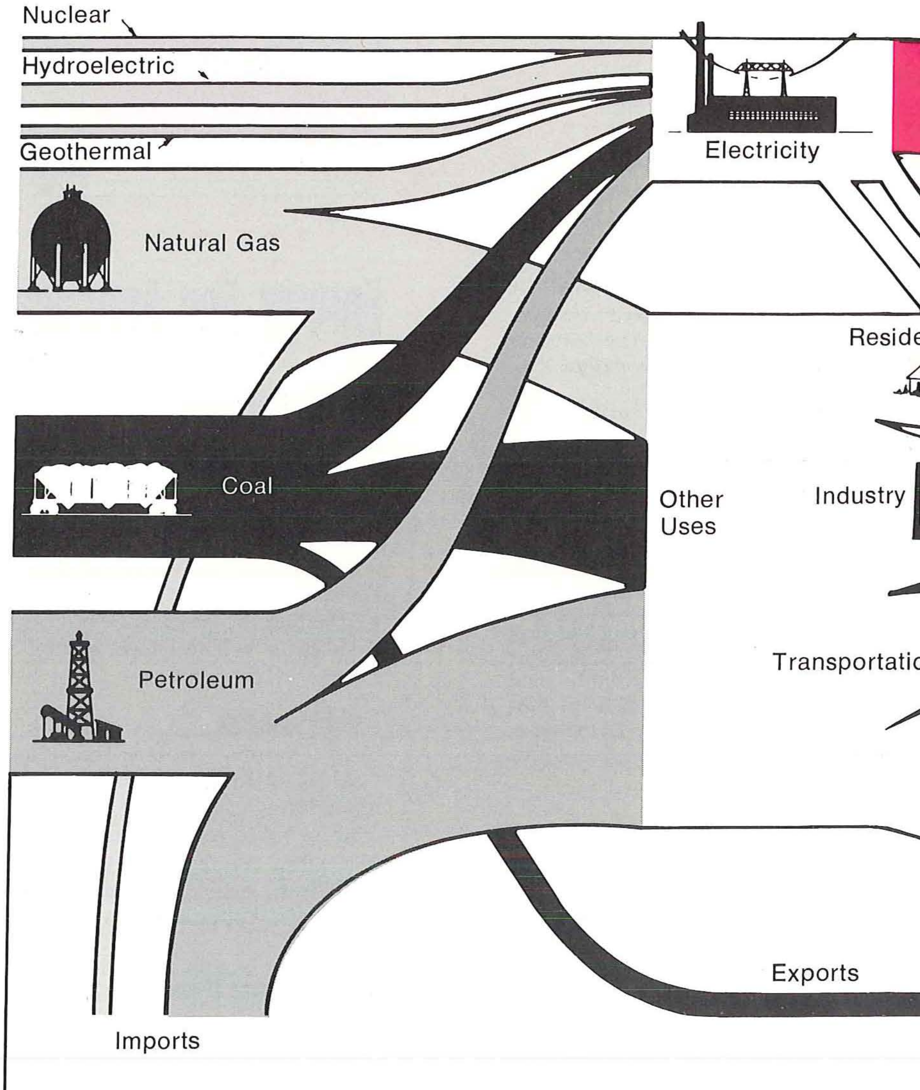
ENERGY SYSTEMS

What We Have and Where It Goes

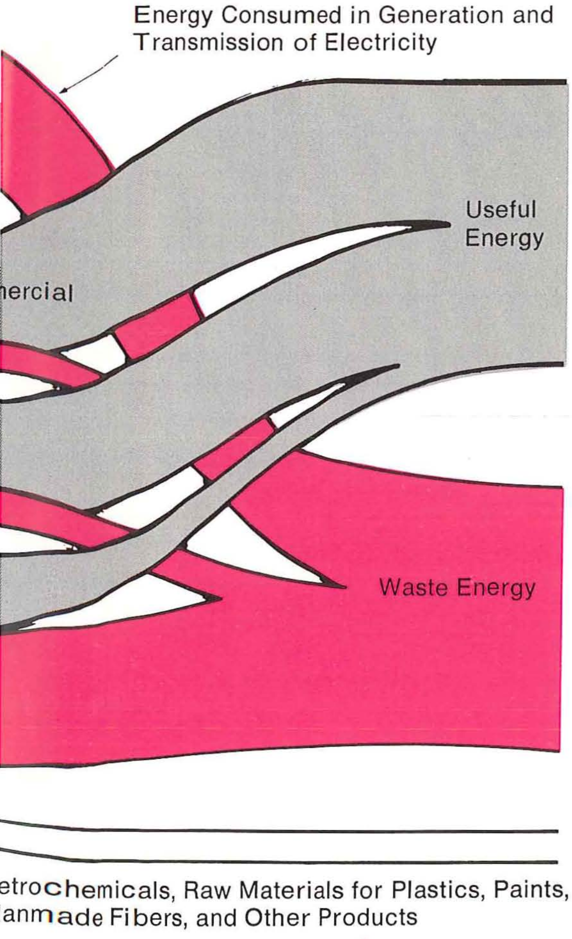
The supply and demand of energy is strongly related to market conditions. At any given price for fuel there will be a given economically recoverable reserve. When prices go up, reserves, as well as withdrawals from reserves, go up too. Coal producers find it profitable to dig deeper, and oil producers return to shutdown fields for secondary or tertiary recovery of petroleum. Further, as fuel prices rise, industrial consumers tend to cut back consumption by shifting to less energy-intensive technologies, while individuals conserve energy by reducing thermostat settings and gasoline consumption and following the other energy-conserving practices we all became so familiar with recently.

Because of these relationships, we know less about our energy resources than we'd like and find it hard to predict the effect on conventional energy supplies and demands that new technologies might have, since the introduction of such new technologies will disrupt the current market price and quantities. In an effort to quantify these relationships among fuels and prices, NSF is supporting a number of studies.

Coal is once again assuming tremendous importance as the world's low-cost



U.S. ENERGY: WHAT WE HAVE AND WHERE IT GOES



The energy system. Energy policy questions eventually come back to this chart. On the left are the energy supplies—predominantly coal, natural gas, and petroleum; in the center the ways we consume it; and on the right, perhaps most revealing of all, how much of it is wasted.

crude oil is becoming depleted. U.S. coal may become the world's dominant low-cost fuel 20 years from now. But the use of coal is hindered by serious environmental effects, not only in the combustion, but in the mining as well.

A group at the University of Tennessee, in cooperation with the Appalachian Regional Commission and the Tennessee Valley Authority, has a number of research projects addressing coal mining. One of their goals is to determine the true social cost of coal mining in Appalachia and the Western States. There are now ways to quantify environmental costs for coal mining—cleaning up streams and reforesting stripped areas—but the burners of coal aren't assuming the full cost of returning the coal areas to their original form. These costs, added to the market cost, result in a higher social cost. But there is also an offsetting adjustment. Increasing production of coal in regions of Appalachia where unemployment is high may result in a decreased social cost, because the cost of employing additional workers is diminished by the previous cost of maintaining the worker on unemployment.

In another coal project Mike Rieber at the University of Illinois has been refining our estimates of U.S. coal reserves. Until his work all coal reserves were figured on a tonnage basis, not a Btu basis. But there are many kinds of coal (see "Coal: Liquefaction" on page 30), all with different Btu values. In particular, the desirable low-sulfur coal reserves are dominated by lignite, which has a lower Btu value than hard coals. Rieber has been converting coal reserves into Btu equivalents, using a reference figure of 22.6 million Btu's per ton of coal. His findings are that while we probably have slightly more energy reserves in high-sulfur coal than we had thought, our low-sulfur (less than 0.7 percent) coal energy reserve might be considerably less than supposed.

Energy Systems

Our overall energy system, as the illustration on this page shows, consists of three distinct segments: energy resources; energy consumption (divided almost equally among power generation, residential and commercial use, industrial use, and transportation); and the division of energy into useful work and waste heat. Each of those three sectors is the focus of an NSF energy systems research program. Two additional programs look at the interaction of the elements in the flow: development of systems models and expansion of the energy data base; and, finally, examination of regulatory and policy options.

Several systems studies are looking at the changes in oil and gas supplies as energy prices increase, then trying to predict where the bottlenecks will appear in the supply process (like the current shortage of tractors in the coal business). On a grander scale, a project at Virginia Polytechnic Institute is aimed at developing and applying a world energy model that can show the implications of different international energy strategies on U.S. consumption and production.

Competitions between fuels

Many of the new energy technologies are, right now, fragile concepts still in the heady stages of research planning.

But the recently stimulated interest in their development will lead soon enough to some hard decisions about which are most promising and should be supported most vigorously. Though the initial question hinges on the technical feasibility of individual techniques, the decisions rest on broader bases. Generally, energy supplies are interchangeable, with market and regulatory factors dictating their distribution. New technologies, then, must compete with old ones, and better ways must be found to figure true impact of changes in energy systems.

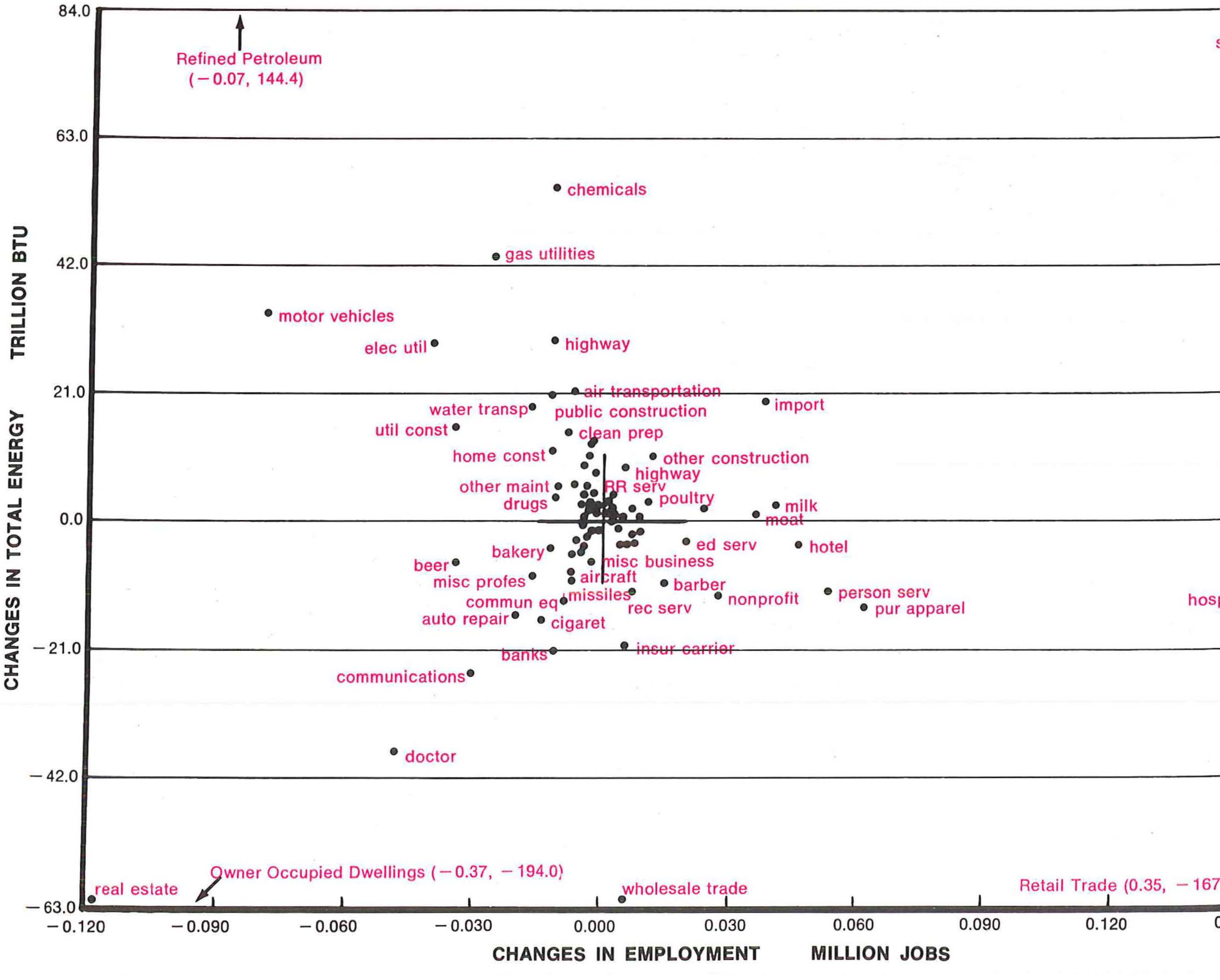
We need forecasting models capable of assessing benefits and costs of energy technology, models that can express benefits in terms of reductions in costs to the United States of its energy bill. One of NSF's prime goals is development of a national model of the conventional energy markets; new technologies, when enough is known about them, can be plugged into the model for evaluation.

It's also possible to use models to evaluate the effect of policy decisions on energy supplies. At MIT Paul McEvoy has designed one to evaluate domestic natural gas supplies. These supplies are strongly regulated right now, with prices dependent not on the market but on the date the gas well came into production, so gas from old wells sells for less than new ones. McEvoy's study shows that if prices were deregulated, the price would jump immediately. But, as a result, more gas would begin to be delivered to the consumer as supplies responded to the market.

In a companion MIT study M. Baughman analyzed the effect on energy supplies of changes in the price of oil. The results, summarized in the table on the right, show that as world oil prices
crease, domestic oil supplies increase
the need for oil imports decreases.
increasing prices also boost demand
natural gas, and natural gas prices c
and reserves increase because of
creased domestic oil exploration.

Baughman's study, begun a year
used a "high" oil price of $10 per ba
three times the price then but somew

Energy and employment. This chart summarizes an economic analysis basec on the U.S. industrial sector for 1963. It shows the changes in total energy consumption and employment (direct an indirect) that would result from a 10-perc growth for each particular industry. The offsetting decreases are apportioned am all other industries. Most industries at th time responded to increases in productio by becoming more energy-intensive and less labor-intensive.



less than current prices. Further studies at higher oil prices may be more predictive of the future, but even the $10 per barrel price shows some important effects. At that price coal would become the dominant fuel for power generation by 1985. And also at that price, U.S. petroleum imports would drop to zero by 1985. In order to meet U.S. energy needs, however, a national investment of approximately $85 billion per year is required for exploration, oil and gas development, and electric generation.

Models are also being developed to understand the impact on demand of various energy conservation strategies. One important question beginning to be asked is what effect large electrical generating plants—with attendant economies of scale—would have on electricity demand, and hence on coal, oil, and gas consumption. NSF is also providing support to several State governments so they can devise energy allocation strategies that take into account the various trade-offs possible between energy uses in their communities.

Impact of Oil Prices on Interfuel Competition

		$5 per Barrel	$7.50 per Barrel	$10 per Barrel
Petroleum imports				
	1980	60%	29%	16%
	1985	74%	39%	0%
Total energy imports				
	1980	27%	12%	7%
	1985	33%	14%	1%
Investments—1985 ($ million per year)		53.1	75.2	86.4

Finally, it's instructive to consider the effects on energy supplies and uses by changes in demand. Almost two-thirds of our energy comes to us primarily in the form of an intermediate product embedded in the things we buy. So, to understand energy we have to understand these intermediate energy flows. Bruce Hannon at the University of Illinois has adapted the input/output model of economics to an energy input/output model. His analysis can show the energy flows between any two industries, the kind of energy source, and how much labor is required for each industry's output.

The model can evaluate the effect on both employment and energy distribution of energy shortages or surpluses. If, for example, the Nation were faced with a five-percent reduction in available energy, the model could show which selective industrial cutbacks would minimize unemployment. This process is, in fact, being used as a planning tool by the Federal Energy Office in its fuel allocation program.

Such a model can also be used by energy-conscious planners to forecast energy and employment changes as a result of changes in outputs of specific industries. For example, a ten-percent increase in the output of the energy-intensive motor vehicle industry, with proportional decreases in all other industries to keep a constant GNP, would result in an annual increase in energy consumption of about 30 trillion Btu's and a corresponding decrease in employment of some 75,000 jobs nationwide. A similar increase in output of the personal apparel industry would increase employment by 60,000 and decrease energy consumption by 15 trillion Btu's per year. The great value of Hannon's model is its ability to account for the indirect impact of energy consumption.

Hannon's model doesn't claim to forecast the kinds of consumer behavior changes that may follow from energy perturbations, though it does show the eventual consequences of changes in demand for products. Actually, the area of consumer optimization is badly in need of more research. In some already done along those lines, the RAND Corporation showed that the poor waste less energy and so would be harder hit by energy rationing than the more affluent part of the population. That study was instrumental in plans laid by the mayor of Los Angeles to exempt the lower third of energy users from a ten-percent electricity reduction plan. ●

ENERGY SYSTEMS

Comparing Options for the Technologists

Some decisions about which kind of energy research and technology should be pursued may rest on fairly obvious circumstances, such as whether it works or whether it's even in the economic ballpark. But other decisions, especially between alternative developments of competing or complementary technology, are much harder. There are advantages and disadvantages to be weighed and the final "best" choice depends on the evaluation of all factors (economics, technological base, environmental effects, impact on balance of trade, employment, etc.). To assist in the decision-making process, NSF has begun a program in comparative systems analysis.

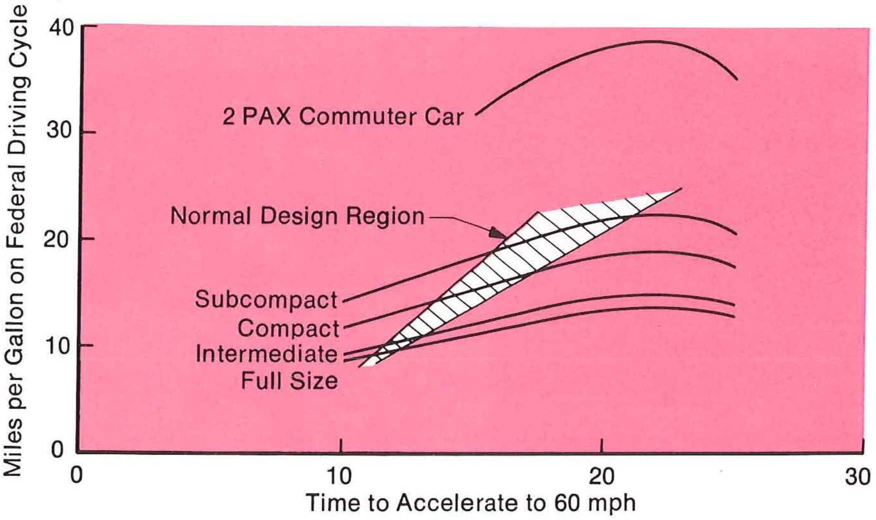
One of the studies to be undertaken soon concerns the comparison between centralized and non-centralized powerplants. A centralized plant, perhaps 10,000 megawatts, could serve multicommunity, perhaps multistate, needs; today's typical ones, on the order of 1,000 megawatts, are community- or regional-focused. The differences are far more than size alone.

A central facility makes big demands on transmission and distribution, but it offers environmental benefits because the power-generating facility can be located in a single spot removed from the metropolitan areas it serves. Another potential advantage is the economy of scale made possible by the size of the installation. Are those advantages powerful enough to make it worthwhile to deal with the institutional problems? Big powerplants would probably involve different public utility companies, each with their own regulations. Operating it would probably require the formation of a consortium of power companies, with the difficulties of joint financing and their different power rate structures. The plant itself may be owned by the consortium, but the transmission systems by each member. It might even be necessary for legislation to be passed to enable these companies to function together.

The alternative, continuing to build small plants, has drawbacks too. The Nation's capacity is now approximately 400,000 megawatts; estimates are that it will be tripled by 1990. Powerplants being built today cost some $600 per kilowatt—which means an average of approximately $25 billion per year just to bring new plants on line. Utility companies are hard-pressed to find that kind of money, so there is certainly an incentive to look for more economical operations in spite of the institutional barriers. So, a first consideration is to sort out the technical, economic, environmental, and institutional issues and identify the research needed.

One step removed from the powerplants are the distribution and transmission systems, which also have great potential for improvement. One intriguing possibility is direct current, rather than alternating current, transmission. Right now there is only one d.c. network in the country, running from Oregon to Southern California. But interest in d.c. nets is growing. Large amounts of d.c. may well be sent with less power loss than a.c.; lower transmission loss means powerplants could be smaller. D.c. also offers lower cost (at distances generally greater than about 300 miles) as well as potentially greater stability in the power grid. But there is an added expense in converters. The d.c. must be converted from the a.c. generated in the powerplant, then reconverted to a.c. for distribution to users. But while the market for d.c. is small now (some industries use d.c.), it may grow in the future.

RELATIONSHIP BETWEEN FUEL CONSUMPTION AND ACCELERATION



Comparing systems. This graph shows how gas mileage is sensitive to the acceleration design characteristics of cars. Smaller cars, unlike full-size cars, are deliberately designed to operate on the more favorable part of the curve, trading acceleration for energy savings. But if different size cars were designed for the *same* performance level, the disparity in fuel economy would be reduced substantially. Also shown is the curve for a theoretical two-passenger trunkless car with a number of possible energy-saving adaptations.

Another energy system, with great potential for improvement, is automobile propulsion. Here the options are varied, and a total systems study, from fuel to wheels, is needed. The initial work will be centered on the internal combustion engine, with new or modified fuel, then probably move on to other parts of the system. Among the things worth looking at are:

- Reductions in acceleration rates, which can decrease energy consumption considerably in urban driving.
- Continuously variable transmissions, which are claimed to be able to save 25 percent of the fuel being used.
- Retrofitting current cars with changed carburetion and fuel distribution systems, again trading some acceleration for efficiency.
- New fuels—methane, methanol, catalyst beds to make hydro and add it to the fuel for m efficient operation and better us limited petroleum resources.
- Flywheels as energy storage dev in cars.

Comparative systems analyses, pecially when the systems involve developing technology, require a s data and information base. As a fo dation for the studies, NSF is support Oak Ridge National Laboratory's pro to compile abstracts of current energy search. This information is dissemina through the monthly journal, *Energy A stracts*, and through an annual *Invent of Current Energy Research and Dev opment* published by the Subcommit on Energy of the U.S. House Commit on Science and Astronautics. ●

ENERGY SYSTEMS

Conservation

Conditioned by long-time cheap e ergy, we've had little econom motivation to use less. Now, a for the foreseeable future, we do. N is supporting a diversity of studies sort out conservation techniques, to d termine and demonstrate those that a the most feasible, and to recommen energy-saving techniques for future d velopment. Although there are some in portant technical means of conservi energy in power generation (see, pa ticularly, "Generating Electricity: Was ing Less" on page 33), most of the po sibilities in the other three demand area (residential and commercial energy us industrial use, and transportation) hav strong, even dominant, institutional com ponents.

An excellent example comes out of study by Robert Socolow at Princet University of residential energy use a 3,000-unit housing development in Ne

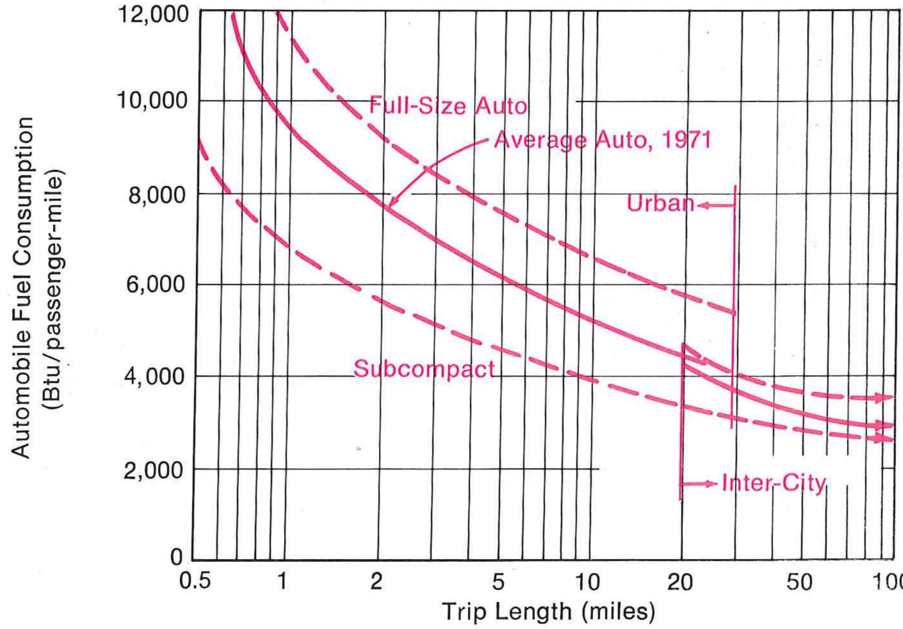
Jersey. There he finds that some households use two or three times the energy of virtually identical households in the community. A study done at Oak Ridge National Laboratory of house cooling in Atlanta, Philadelphia, and Minneapolis suggests how much discretion an individual household can exercise. In the typical mid-temperature ranges, raising the thermostat three degrees will reduce energy used in air-conditioning by nearly 30 percent, almost 10 percent per degree. Several results of other Oak Ridge studies completed last year are already well known to many people: Reducing the highway speed limit nationally from 70 to 50 mph could save $0.3x10^{15}$ Btu's out of a total U.S. energy consumption of about $64x10^{15}$ Btu's per year, and lowering residential heating thermostats 6° F and commercial ones 10° F could save $4x10^{15}$ Btu's per year. Obviously, individual attitudes can have a great effect on conservation.

But changing attitudes and habits, even when people will save money as a result, is a difficult job. A different conservation technique is to make technological means available to people. A study by Oak Ridge and Hittman Associates shows that energy use in average homes could be reduced by about 40 percent at an additional initial construction price of three percent. In many electric homes, with their high energy bills, insulation (3½ inches in the walls, 6 inches in the ceiling) will more than pay for itself. An electric homeowner in Atlanta, for example, would save $90 a year, even after all costs were considered. This study has made a significant contribution to understanding of insulation requirements in different parts of the country. Results are being used as input to HUD on needed changes in the insulation requirements of the FHA Minimum Property Standards for one- and two-story living units. Sidney Firstman at Aerospace Corporation is studying energy conservation in the public housing sector, seeing how the different physical and management structures of large urban apartment complexes can be modified to reduce energy waste.

A homeowner might pay $1,000 a year for residential energy, but if you're paying an annual energy bill of $5 million, you may see the energy conservation problem a little differently. At Ohio State University, which has such a yearly bill, Charles Sepsy's group is making a detailed study of energy use in OSU's new Legal Center. As a result, they've come up with new operating plans for 23 of the school's buildings that should lead to a 30-percent reduction in energy use on campus. The guidelines will be available for use by other institutions for their energy conservation programs. In addition, they have started construction of a new energy conservation house, expected to be open in the fall of 1974.

Perhaps the largest educational user of energy is the New York City School System with more than 1,000 schools. As a result of an NSF grant to the Board of Education, architect Richard Stein is currently surveying energy use in the city's schools preparatory to design, construction, and operation of a new school with low energy use. Among his firm's early conclusions is that present energy use varies widely and somewhat unpredictably from school to school, much as Socolow found for the New Jersey community. Stein suggests that, as an early measure, a simple operations manual for the maintenance staffs of the schools could result in significant energy savings.

About as much energy is consumed for transportation as for residential and commercial use, but a far greater proportion of it is wasted. Without considering any design changes in vehicles (discussed in "Comparing Options for the Technologists" on page 5), the Oak Ridge group has suggested some priorities for energy savings in transportation. Their analysis of automobile energy consumption (52 percent of all transportation energy) leads them to suggest two basic energy-conserving tactics: Discourage use of cars for short urban trips, and discourage use of full-size cars, especially in urban areas. A two-mile urban trip uses more than twice as much energy per passenger-mile as a two-mile intercity trip. And a two-mile urban trip in a full-size car takes three times as much energy as the two-mile intercity trip in a subcompact car.



Big vs. small, short vs. long. For all cars, longer trips lead to greater per mile efficiency, and at inter-city distances the differences between subcompact, average, and full-size cars grow smaller. But in city driving, and especially for short trips, the subcompact car—even with reduced seating taken into account—has a marked fuel consumption advantage over the full-size car.

In looking at airplane travel the Oak Ridge group found two clear opportunities for large savings. If passenger loads were increased by 20 percent, 15.9 percent of the airplane fuel would be conserved. Or, if half of the trips less than 200 miles were shifted to train or bus, 6.1 percent of the airplane fuel would be saved. And a California group, applying aerodynamic design to trucks (which use 12 percent of the transportation energy), thinks a billion gallons a year could be saved by retrofitting devices on the Nation's trucks at a cost of $150 to $250 per truck.

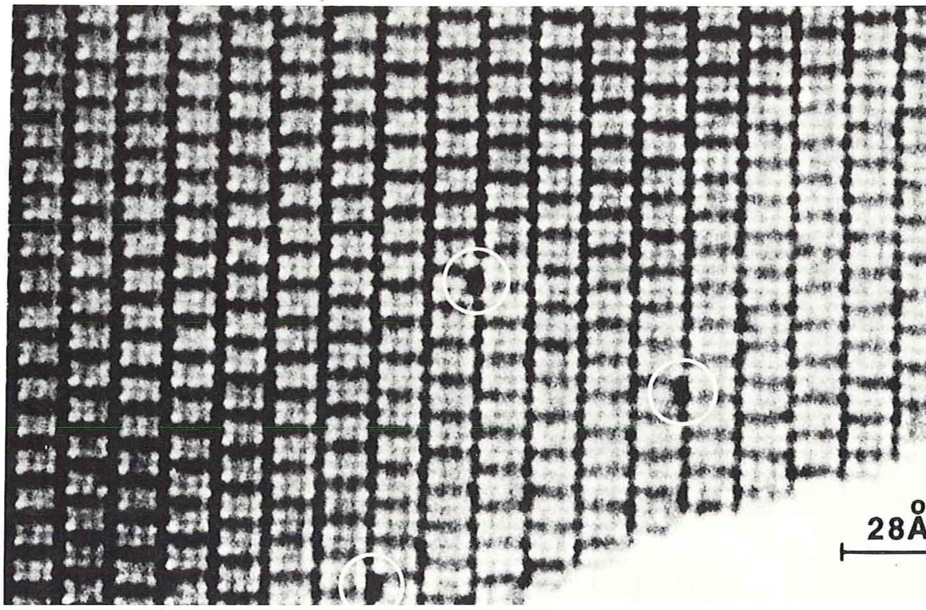
Finally, a group at Drexel University is trying to make energy efficiency analyses of all segments of the urban system—residential, commercial, and industrial—to see where and how waste energy can be reclaimed. ●

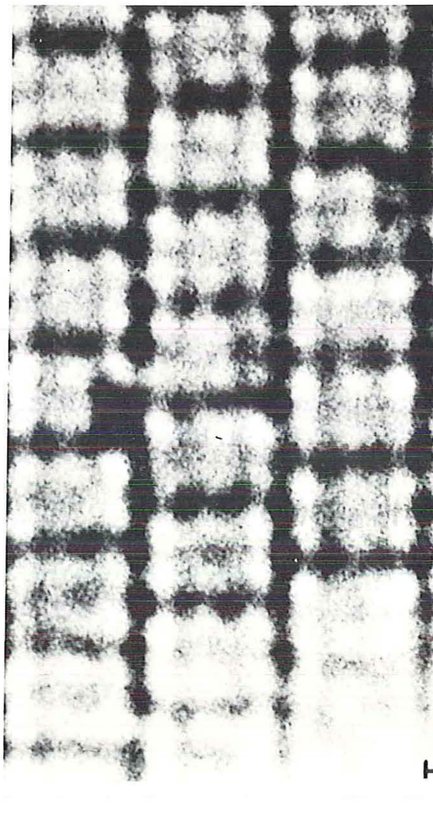
ENERGY-RELATED RESEARCH

Strengthening the Weak Links and Making New Chains

The performances of systems that convert energy from one form to another—nuclear to electric, oil to hot air, sunlight to cold air, to name a few—are limited by the properties of their materials. Better materials, then, should result in better energy systems. Research in materials science can be expected to lead to improvements in two areas: materials that are stronger at extreme temperatures, pressures, and in harsh chemical environments; and materials that conduct or insulate energy better.

Some of the most serious materials problems occur in high-temperature systems, and certainly some of the promising new energy techniques await materials that can operate at elevated temperatures. A particularly thorny problem exists where sudden changes of temperature take place. Examples occur in some systems such as gas and steam turbines, heat exchangers, coal combustion chambers, and magnetohydrodynamic converters. Here the problems are aggravated by the simultaneous actions of chemical corrosion and abrasion. In a number of laboratories, scientists are experimenting with new metals and ceramics at extremely high temperatures, measuring their behavior under sudden thermal shocks and when acted on by





Strength of materials. Electron micrographs of thin flakes of niobium oxide show defects in the crystal structure. Each white dot in the lattice pattern represents an octahedron of oxygen atoms containing one niobium atom. The large black spots are point defects in the material, which are displacements of niobium atoms from their normal sites caused by an excess of oxygen.

corrosive agents of the kinds that might be expected in tomorrow's machinery. And to help develop a theoretical framework for materials behavior, they're also looking at the microscopic processes in materials.

Other energy systems, such as fusion and fission reactors, have additional problems. Metals become brittle as hydrogen is forced into them or when subjected to too much radiation. To predict and prevent that kind of failure the scientists must find out how atoms move around within the structure, what voids appear in the crystal structure under bombardment, and what atomic arrangements can give the materials more strength.

Energy-Related Research

There are two fundamental ways to think of energy. One is as a commodity, previously cheap and plentiful, now in short supply. Hence, development of new supply sources—described in other parts of this magazine—is being stimulated in response to changing market demands. The other way to think of energy is as a basic component of nature, and interest in this kind of energy has always pervaded scientific research. So it comes as no surprise that large segments of traditional basic research, though initiated primarily for understanding diverse phenomena, bear also on the problems of new energy technology. One can't predict precisely how these research pursuits will link with technologies (though in some cases the potential applications are apparent). But if the past is a reasonable guide, our future energy supply mechanisms—whether wholly new or just more sophisticated versions of current or planned technology—will have antecedents in basic research being done today.

Surface reactions are poorly understood, and many needs exist for research in this field. Studies of surface phenomena are greatly encouraged by the need for better catalysts, because in many catalysts almost all action happens on the surfaces. Studying the effects of catalysis will help determine why some atoms bind more to some surfaces than to others, or what are the interactions of ions as they are adsorbed onto the surface. A better understanding of surfaces and the adsorption of atoms would increase our ability to use catalysis in energy-related processes. Surface studies also help in the search for new optical coatings for trapping solar energy at high temperatures.

Superconductivity—the peculiar quality of some electric conductors at ultralow temperatures to transmit current with no power loss—was a curiosity of the physicists not long ago. Today engineers are anxious to put superconductivity to work in energy transmission and machinery but, again, fundamental materials problems limit what they can do.

Superconducting materials commonly are cooled to a temperature of —269.2° C (less than four degrees from absolute zero) by liquid helium. The disadvantage of that process for practical applications is the expense and, eventually, scarcity of helium. But recent research has developed a metallic compound that is superconductive at a significantly higher temperature: —250.7° C. At that temperature liquid hydrogen (at a temperature of —252.6° C) can be used as the coolant. A vigorous area of research these days is to improve these higher temperature superconductors and to continue trying to devise even "warmer" superconducting or highly conducting materials.

Conducting materials have usually been formed by equilibrium processes: heating and cooling them to reach the proper condition. Now new techniques have been developed for forming these materials by nonequilibrium processes such as sputtering and ion implantation. In sputtering, materials are spattered onto cold substrates in such a way that the materials solidify very quickly. In ion implantation, metallic ions, usually hydrogen, are shot into a substrate where they become imbedded. Several new materials with higher superconducting transition temperatures have been produced by these processes.

In trying to understand the mechanisms of superconductivity, researchers are studying various problems such as magnetic impurities in the materials, the presence of hydrogen in metals, and the crystalline structure of different materials. Metal alloys are now being stretched so thin they become virtually two dimensional, even one-dimensional in their electronic structure; and in these cases they exhibit a variety of electrical and magnetic properties that may lead to increased superconductivity.

Research in new materials and thei properties also offers significant potential for storing energy, perhaps the mos aggravating problem to be faced i matching energy supplies with demand Research on the efficient storage o energy in chemical, electrical, and hea forms involves many phenomena: electrolyte behavior, ion conductance, an superconductivity. ●

ENERGY-RELATED RESEARCH

Fuel In/Power Out: The Steps in Between

Many physical and chemical processes that are still only partially understood are involved in even the commonest energy conversion systems. For instance, generating electricity by burning oil involves chemical refining, combustion processes, fluid flow, heat transfer, and thermodynamic cycling—all areas of active fundamental research. And because at each stage of the conversion process energy is lost, better understanding of even single phenomena could give systems designers an opportunity to reap more useful energy from the fuel.

True measures of energy conversion efficiency involve more than the generating plant itself, and during the years of cheap energy, many industrial processes allied to energy production were deliberately designed for heavy consumption of energy in order to reduce initial capital costs. This was particularly true in industries such as metal forming and chemical process engineering, parts of which are now seriously threatened by the prospect of more expensive energy.

In recognition of the weaknesses of current chemical processing technology, a number of scientists are investigating more efficient control systems to increase the energy and decrease the cost. For instance, it looks as if efficiencies of chemical and petroleum processing plants may be increased by deliberately pulsed, rather than continuous, operating conditions. This is made possible now by the availability of reasonably priced high-speed electronic controls and specialized computational equipment. Other areas especially ripe for new advances involve flotation treatment of ores to upgrade their quality, experimental techniques for desulfurization of coal and oil, and determining the relationship between catalysts and the surface structures upon which they act.

Research in the little understood field of catalysis—the use of an agent to speed up chemical reactions—offers great potential in many energy processes, notably the gasification of coal or production of hydrogen from water. Scientists are now able to increase the rates of many important reactions as much as 100,000,000 times with selected catalysts, and they are developing ways to accurately select particular catalyst mechanisms from among competitive reaction dynamics. Such tailoring of catalysts could increase the efficiency of processes and minimize waste of energy and materials.

There are significant savings of energy possible in industrial processing through innovations that either reduce energy consumption or bypass high energy-consuming steps. For instance, the efficient distribution of electricity from powerplants with reduced loss of energy is under study, as well as the conversion of battery-stored energy to mechanical energy.

Modern nuclear powerplants are likely to play an important part in meeting near-future electricity needs, but the problem of supplying them with fuel is troublesome. It takes a large amount of energy to separate U^{235} from natural uranium. Researchers at the University of Southern California are working on a possible technology called the jet membrane separation process. This involves the expansion of an easily condensable jet gas into a background region containing an isotopic mixture to be separated. Its significant advantage is the relatively small amount of energy required. It may be possible to apply this technique to the problem of enriching uranium fuel, driving it with low grade thermal energy (solar energy or even powerplant waste heat) and thereby having a significant impact on the overall energy efficiency of nuclear reactors.

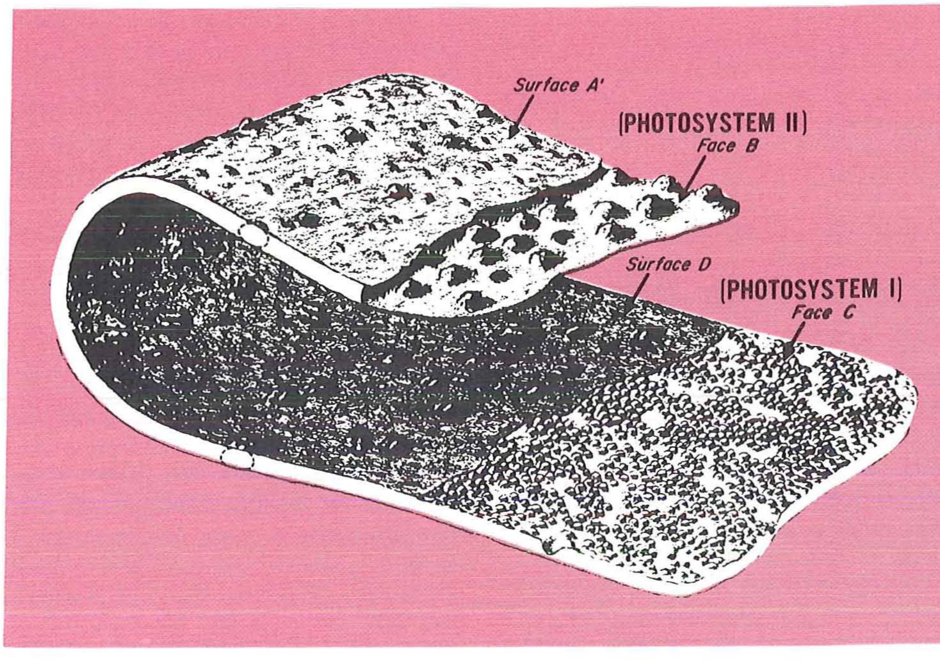
A number of advanced power devices demand a better understanding of plasmas—hot gases composed of charged particles—ions, and free electrons. Plasma physics comes into play in nuclear fusion, in magnetohydrodynamics, in thermionic cells, in lasers, and in exceptionally high temperature chemical processing. These energy-related uses of plasma generally require the same basic knowledge: how to keep the plasma where it is wanted, and how to keep it clean and hot. Along with laboratory experiments, much can now be accomplished by computer simulation of plasmas (See "Too Many Bodies" in *Mosaic*, Fall 1973). This has added a potent analytical process to the theoretical and experimental processes under way to understand energy-related plasma dynamics. ●

ENERGY-RELATED RESEARCH

Plants Do It: Why Can't We?

The living things of the Eart
plants, animals, people, bacteri
have remarkably efficient and ad
tive methods of gaining energy fr
natural resources, converting it
growth, motion, and other life proces
storing it, and converting it into ot
energy forms for use by other syste

The fundamental biological proc
that supplies man's energy is photos
thesis by plants. This process inc
porates the Sun's energy into a biom
from which man obtains food and fu
for heat and power. Other biologi
processes produce other fuels such
methane from organic wastes, or in so
cases hydrogen. These microbial c



Efficient energy converter. Plants convert the energy of sunlight into food and materials with chloroplasts containing a folded and tightly packed system of membranes, the grana. This model of grana shows the locations of aggregates of light-harvesting pigments and proteins on the inner and outer faces.

versions are immediately useful in dealing with organic wastes, but might also be coupled with photosynthesis to provide new fuel sources.

There is obviously much we can learn from the plants, and through better understanding of plant energy utilization we may arrive at more efficient methods of producing energy for ourselves. For example, if we can determine the reasons that some plants photosynthesize more efficiently than others, we may be able to increase plant productivity. That, in turn, can improve crop yield at a given energy input, and also increase available materials that could serve as primary or secondary energy sources (See "Bioconversion: Energy Farming and Recycling Wastes for Power" on page 19).

Another key area of bioenergy is nitrogen fixation—a natural process wherein some plants obtain their own essential nitrogen supply from the atmosphere (See "Protein from Air" in *Mosaic*, Vol. 4, No. 4). Scientists are investigating methods of extending the nitrogen fixing capability to other plants that do not normally fix nitrogen. If that could be done, substantial energy now expended in producing and distributing commercial nitrogen fertilizers could be saved.

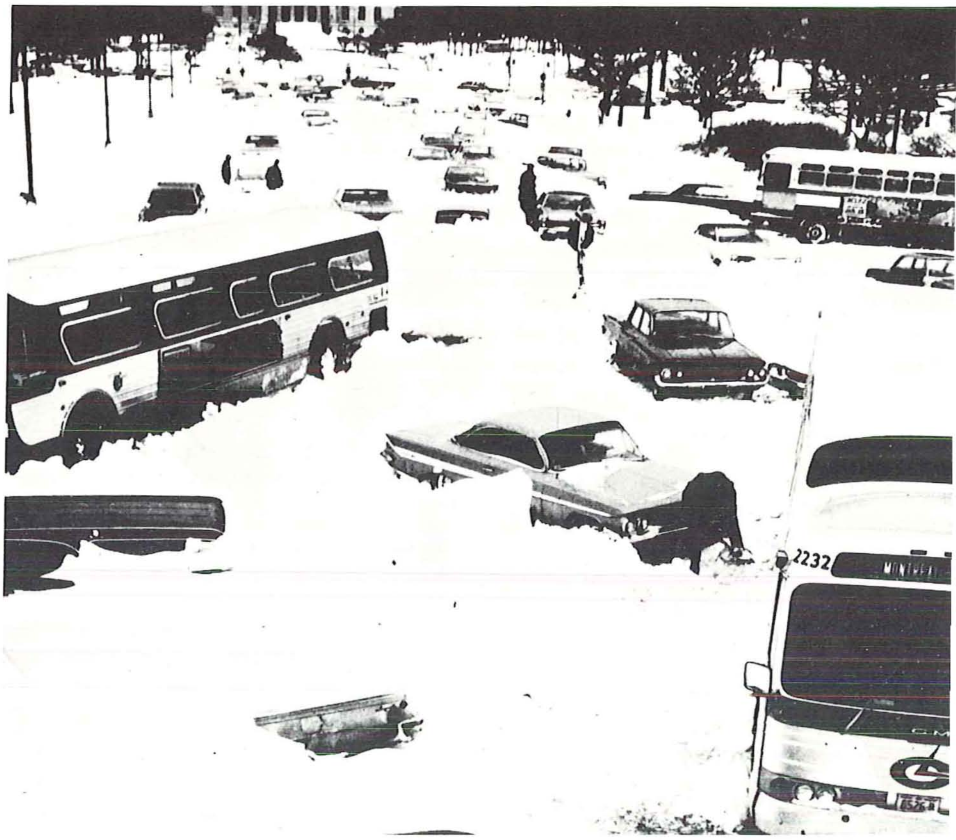
Molecular biology directly involves energy transduction and catalytic mechanisms used by living organisms. The enzymes which nature has evolved to serve as catalysts in biological systems have been the most efficient and specific examples known to man. Knowledge of enzyme structure and properties has now reached the point where selected enzymes may be used in industrial applications, rather than microorganisms, as has been the case in the fermentation industries. In addition, knowledge of the essential structural features of enzymes is now being used by chemists to synthesize catalysts which may rival or surpass the enzymes in effectiveness. ●

ENERGY-RELATED RESEARCH

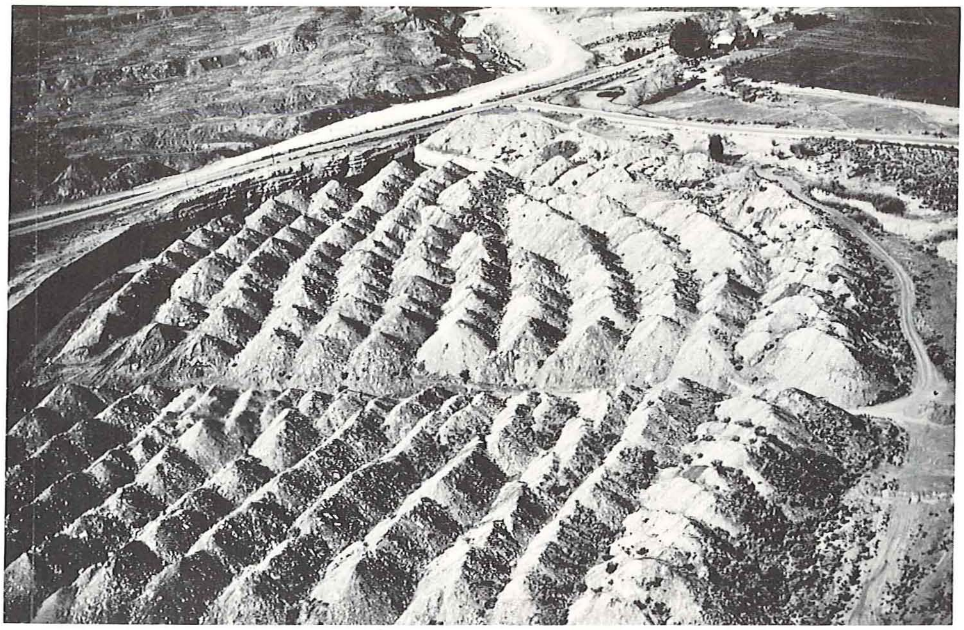
Reading the Environmental Signs

It seems almost silly to have to point it out, but energy demand is affected by weather. And because of that, many decisions regarding the allocation of energy resources have to rely on the present state of the art in weather forecasting. For example, should your town mobilize its snowplow force in anticipation of a midnight snowstorm? Alrea
daily weather predictions attempt
assist with such decisions. But wh
about the longer time scales? Shou
you buy an extra cord of firewood f
next winter? Should hydroelectric ge
erating capacity be conserved in antic
pation of droughts? How much of th
Nation's crude oil supplies should b
allocated to production of heating o
and how much to gasoline? Such dec
sions require an ability to foreca
climate changes—an area in which re
searchers have much to learn.

Research in atmospheric sciences ove
the past decades has improved ou
understanding of the "causes" of weathe
and has resulted in increasingly accura
forecasts over time spans of sever
hours to a few days. (It's the weather
man's lot, though, to be in a professio
where people never remember when he'
right; only when he's wrong.) The are
of particular interest for future researc
is long-term forecasts, because we ar
now developing the tools to acquire an
handle the immense amounts of dat
that global weather research entails
Accurate large-scale climate forecasting
ranging from 5 to 50 years, if achievable
would be an obvious advantage in th
future as we plan the types and location
of energy resources to be developed.



Spinning wheels. Research in improving short- and long-range weather forecasting could forestall energy wasted when preparations don't match conditions and permit better seasonal allocations of energy supplies.



Energy and environment. Research in ecology and environmental effects will provide a framework to consider the pressures for new fuel extraction priorities, technologies, and sites, and will help guide operations like this Colorado strip mine to minimize environmental impact.

Two other areas of basic atmospheric science are emerging as useful to new energy technology: solar and wind dynamics. Variations in solar radiation—caused by variations in the Sun itself, local climatic conditions, or amounts of particulate matter in the air—affect devices for using solar energy. Studies in regional climatology and large climate changes over many years can indicate optimum locations for establishing facilities that can use solar or wind energy. On the other hand, researchers are also assessing the effect that new energy technologies might have on the atmosphere.

Within the magnetosphere, several phenomena occur that are related to energy and weather on Earth. Scientists are studying how energy from the Sun is coupled through the Earth's magnetosphere, and what resulting effects occur on climate and weather. Also, more information is being accumulated on geomagnetic storms and how they trigger relays in electric power grids, causing power failures, and how they black out radio and telephone communications. The magnetosphere offers a promising space laboratory for further studies of plasma energy, such as the transfer of energy between magnetic fields and particles, particle acceleration, and propagation of energy.

The environment

The interaction between man's energy use and the environment is still poorly understood, but clearly important. Energy systems release heat, moisture, liquid and solid wastes, and toxic gases into the earth, air, and water. And now, with the use of new materials and methods for producing energy, there will be new stresses—different mixes of methods of extracting resources—such as more strip mining geothermal extraction, oil shale processing, and offshore drilling for minerals and oil.

To clarify the picture of energy impact on environment and visualize some of the trends created by new changes in the energy situation, scientists first need to know how ecosystems behave in natural circumstances. Under the NSF-supported International Biological Program, scientists have in the past five years begun to gather data on the natural dynamics of plant and animal communities in forests, tundra, grasslands, deserts, and lakes, with the detail and extensiveness needed to develop models which will predict the responses of different kinds of ecosystems to environmental change, including energy-related stresses. With such tools, man can better assess the potential losses of renewable resources such as forests and other plants from the ecosystems as a consequence of the exploitation of nonrenewable energy resources and the use of sites for energy systems operations and depositories for waste. ●

ENERGY-RELATED RESEARCH

Hot Prospects for the Geologists

Without exception, all the exi ing technologies for supplyi us with energy have had i portant inputs from the earth scientists in finding fuel, in selecting powerpla locations, or both. Oil and gas explo tion is so much a part of energy dev opment that we tend to ignore the c going geological research into bet prospecting methods when we think energy-related research. According predictions, there are vast, untapp petroleum resources in hitherto remo locations, notably under the seas, b also under polar lands. Tapping them, we can, will be aided by a better unde standing of how oil deposits are relat to geologic structures, and how tho likely structures can be accurately d tected under difficult exploratory cond tions.

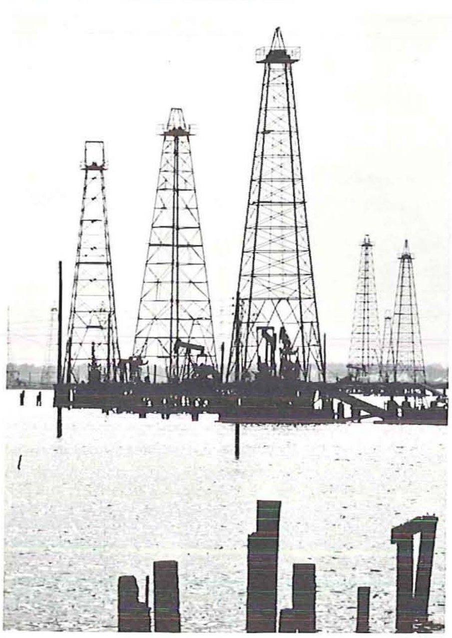
Closer to home, geologists are seei their earlier investigations into he gradients in the Earth's crust becomi the basis for research into new geothe mal power sources. Reflecting an u surge in interest in Earth heat, NS supported geologists are measuring t radial and lateral distributions of abno mally high heat sources near the Earth surface. Also, if dry heat contained shallow rocks can be economically e tracted, it will represent a major ne energy resource.

"Hot spots" can be detected by aeri infrared surveys or other thermal man festations. They can then be delineate by measurements of local changes in th Earth's gravitational and magnetic fiel and in the electrical conductivity water-saturated sediments. Geotherm anomalies can also be found by locating areas of seismic noise, because in certain areas microseisms have amplitudes too high to be normal and are thought to be generated by a geothermal reservoir.

Reaping hot rock geothermal energy will require the circulation of a fluid, probably water, through the rock. The engineers will have their hands full at the surface protecting the power-generating equipment against the corrosive fluids from below. Geologists are trying to give them a headstart by determining now what that deep geothermal chemical environment will be and what the resultant fluids will be like. One group, for example, at the University of California, Berkeley, is using a computer simulation to predict chemical changes in waters flowing through hot rocks.

Other studies to determine the sources and pathways of fluids in past and present geothermal systems are being done by a group at Caltech. Using isotope analyses, the scientists have shown that, in the past, large plumes of circulating surface waters have existed around near-surface masses of hot molten rock, forming "fossil" geothermal systems. The same techniques are also being used in modern geothermal systems to determine the amount of surface waters that have been incorporated into the geothermal fluids. ●

Barreling along. In spite of renewed interest in coal and new interest in geothermal energy, oil and gas remain our major fuel source. Development of new domestic oil and gas reserves will draw on results of current geologic investigations and exploration techniques.



New energy policies, choices. How will we react?

ENERGY-RELATED RESEARCH

The People Factor

In the past 30 years, technology has wrought changes in the economy, living standards, medicine, education opportunities, lifestyles, and countless other features of American life. The relationship of these changes to the increase of energy consumption is generally recognized, but exact understanding is elusive. Obviously, policy decisions regarding energy—its allocation and its conservation—need such information if the most effective actions are to be taken.

To relate energy to such national parameters and to develop better economic theories concerning availability, use, and regulation of energy, NSF is supporting work in a number of social science areas. In one, for instance, econometric models are being developed to predict the impact of various energy supplies and prices on the U.S. economy on foreign trade and policies, as well as on the environment. The models also help define the role of energy in changes of the Nation's population and economic growth.

In another area social psychologists are developing techniques for determining the attitudes of people, their responses to energy availability and regulation, and their motivation and reaction to changes. In larger projects, social surveys are being made of national attitudes to determine how people respond to alternative lifestyles and to increasing difficulties in transportation, heating, and other energy-involved processes. Information like this would indicate what kinds of social reactions might occur as a result of changes in energy use patterns, and would also give planners an idea of what public preferences are.

The present problem of energy shortages is not caused by decreases in domestic production but by constantly growing energy demands. What sort of demands are these? Who makes them? Where are they? What do they affect? As they fill in some of these answers social scientists will be able to determine national trends in these energy demands. By developing more sophisticated models they hope to predict effects of alternate regulation policies on the trends. ●

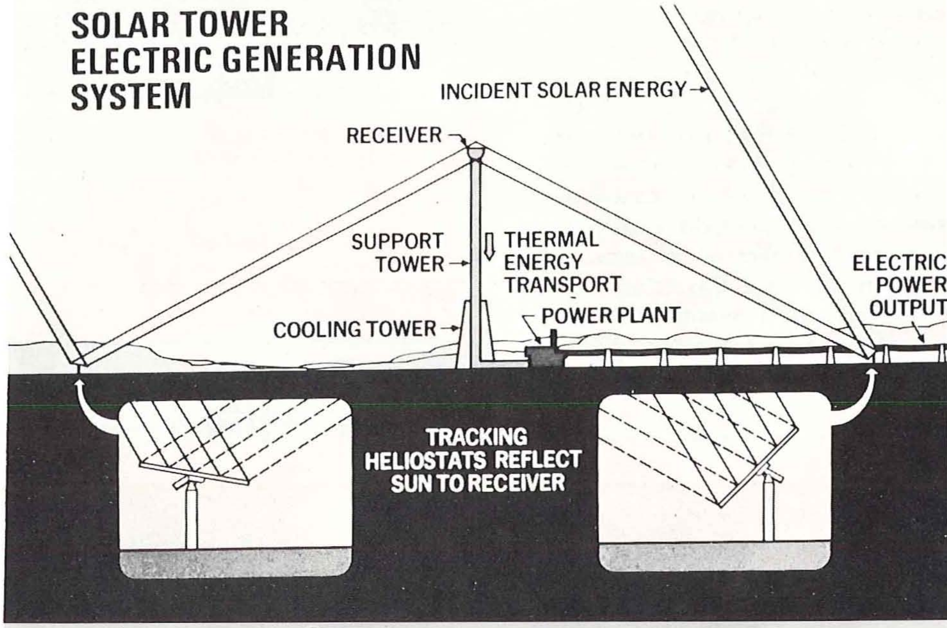
SOLAR ENERGY

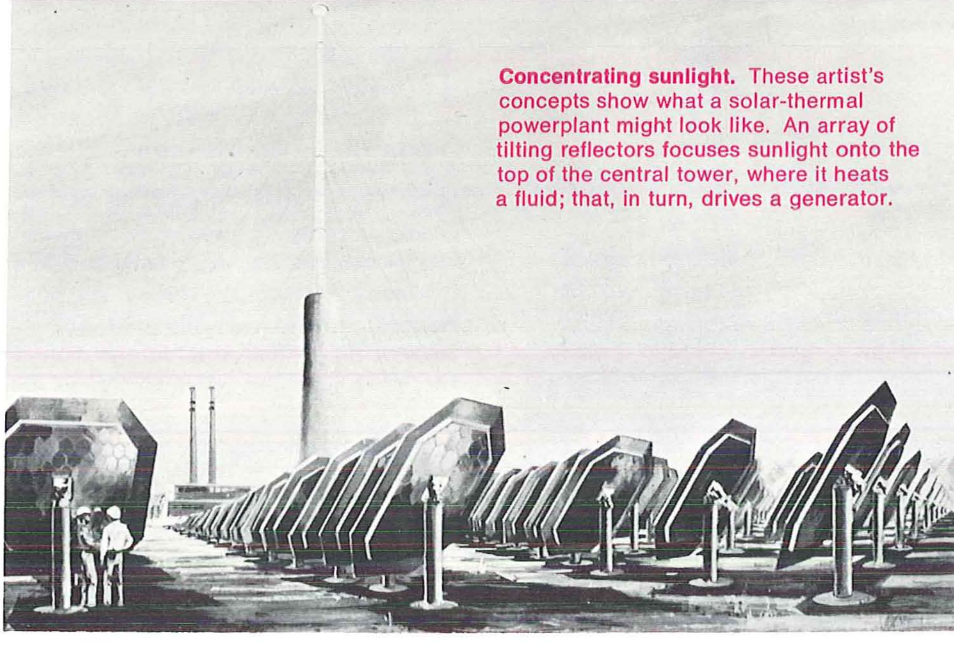
Solar-Thermal: Stoking the Boilers With Sunshine

Sunlight can be hot. Frying eggs on an automobile hood in the Arizona noonday Sun leaves no doubt about that. But the technological path from the hood-cooked egg to one fried on a solar-powered electric stove in snowbound Maine is a long one.

Not the least problem is that of choice—there are so many attractive alternatives to pursue in using the Sun's heat as a substitute for fossil fuel in a generator's furnace. The situation is much like the early days of nuclear power when reactor concepts proliferated. Today, NSF's main task is selecting the best solar-thermal powerplant concepts for further research and prototype development.

Sixty years ago solar heat powered a 50-horsepower steam engine at Meadi, Egypt. Five parabolic trough reflectors, each 205 feet long and 13 feet, 5 inches across, concentrated sunlight on water





Concentrating sunlight. These artist's concepts show what a solar-thermal powerplant might look like. An array of tilting reflectors focuses sunlight onto the top of the central tower, where it heats a fluid; that, in turn, drives a generator.

pipes running down their middles. The low-pressure, low-temperature steam drove engines which pumped irrigation water. There have been no experiments of comparable size since.

Solar power has not languished because we don't know how to use it. There is no overwhelming technological barrier such as that existing in fusion power. Instead, the greatest barriers have been relative cost and reliability. Now the rising prices of fossil fuels encourage us to reconsider the use of the Sun's rays to heat boilers.

Modern solar-thermal powerplants will capitalize on precision Sun-following mirrors, better heat-absorbing surfaces, plastic Fresnel lenses, and other techniques that didn't exist for the 1913 Meadi powerplant. We are now ready to lay plans for constructing megawatt-size solar-thermal powerplants and test them against conventional fossil-fuel plants in terms of economy, reliability, and lifetime.

There are two attractive avenues of development. The first is to devote solar-thermal plants solely to the generation of power. The second is to reap a combined harvest of electricity and heat.

In the first instance, only a fraction (less than one-third) of the energy in sunlight is put to use; the remainder is discarded. The second approach, the so-called "total energy" concept, is based on the eminently practical philosophy that if we are going to all the trouble of collecting sunlight, we should use as much of it as we can. One way gives simple powerplants optimized for the generation of electricity; the other uses sunlight more effectively. Both have their advantages.

From flat plate to central receiver

Sunlight is diffuse heat, so solar devices have to be large to capture a useful amount of it. Furthermore, the highest temperature concentrations come from directional collectors, and they must follow the Sun from sunrise to sunset. But the tilting of acres of solar collectors is not so simple, and some engineers opt for simple flat-plate collectors with selective coatings. Also, flat-plate collectors, because they aren't directional, continue to work reasonably well on hazy or cloudy days. Selective coatings absorb and retain sunlight, creating a kind of greenhouse effect in a thin surface layer.

By trapping solar energy in this manner, flat plates with low concentration ratios can heat a working fluid to about 400° F. But 400° F is low compared to the temperatures in fossil-fueled powerplants, which operate most efficiently with steam at close to 1,000° F. So one of the main disadvantages of flat-plate collectors is that no ready-made turbine technology exists for such low temperatures. Water is not a good working fluid in that temperature regime. Organics, such as Freon and toluene, have superior properties, but we have limited operating experience with these working fluids in power-generating equipment.

To get higher temperatures—about 600° F—we can bend flat plates into trough-shaped concentrators—like those at Meadi. The 600° F is still lower than steam temperatures in fossil-fuel plants, but comparable to those in nuclear plants using pressurized water reactors. So steam turbines and associated machinery already exist for this operating regime. In an NSF research project the University of Minnesota and Honeywell are developing troughs four feet across and eight feet long to focus sunlight on a water heat pipe covered with a selective coating of aluminum oxide. Neither heat pipes nor the coatings were available in 1913, and higher performance is expected than that obtained at Meadi.

To boost steam temperatures to 1,000° F and beyond, further concentration of sunlight is necessary, and the fixed trough approach is no longer adequate. Pointable, parabolic mirrors have been made on a small scale since antiquity (Archimedes supposedly set fire to a Roman fleet by using them). The biggest solar mirrors built to date are high in the Pyrenees, where the French have constructed two of them for metallurgical research furnaces. One of the collectors—an array of several hundred small mirrors—is 105 square yards in area and can generate temperatures in excess of 5,400° F. Although not designed for power generation, the French design resembles a solar powerplant concept being supported by NSF called the central receiver.

The central receiver consists of hundreds of automatically pointed collectors distributed around a tower. Sunlight is focused on the top of the tower where heat is absorbed by a fluid and carried below to conversion machinery. A 500-megawatt design of this type, drawn up by the University of Houston and McDonnell-Douglas, would require a square mile of reflectors and a tower 1,500 feet high. Like the mile-long megalithic alignments of Brittany, such a powerplant would be a striking addition to the countryside, with concave metallized plastic petals replacing the crude stone menhirs of antiquity.

A strange coincidence

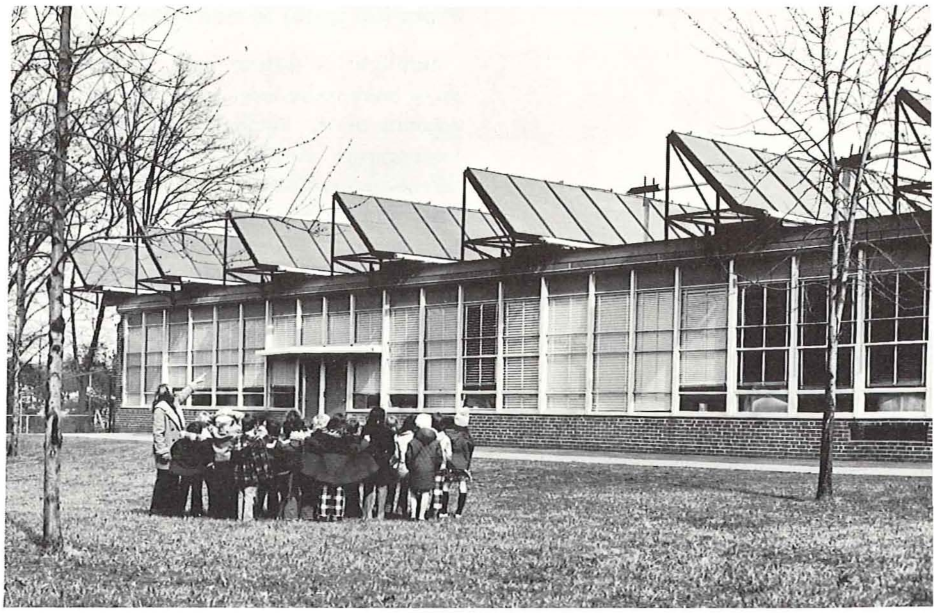
New communities, new shopping centers, and new clusters of commercial buildings spring up constantly all over the United States. These activity centers customarily require 100 to 300 megawatts of energy for heating, lighting, air-conditioning, etc. The ratio between heat and electricity requirements is about 7:1, a ratio essentially the same as that in the output of a solar-thermal powerplant. In other words, the outputs of solar-thermal powerplants are very well-matched to the power needs of these groups of buildings.

This natural coincidence provides an ideal place to create a design that achieves remarkably high efficiencies in using the heat captured. Such a plan could be used only in newly constructed complexes, because this total-energy concept must dominate planning. It would be prohibitive to install the underground ducts, pipes, and electrical cables leading from the central powerplant to all the outlying buildings as an afterthought.

The fuel-saving potential of the solar total-energy approach is high. Excluding energy uses by industry and for transportation, as much as 45 percent of the country's energy is consumed by communities and commercial activities that could be served by solar total-energy systems. ●

SOLAR ENERGY

Heating and Cooling of Buildings: Sol's Comfort Package



Showing it can work. Timonium Elementa School near Baltimore, Maryland, is one of four schools that tried out solar heatin systems in the past winter. Heat is collected in water flowing through the rooftop panels, pumped into a storage tank, and then used to heat classrooms.

In a few favored spots on the globe, Sun and weather combine to create a perpetual Eden. But elsewhere, where man can only aspire to Eden, he must collect and then burn fossil fuels for heating and cooling to balance the excesses or deficiencies of climate. That seems a shame, because nearly everywhere the Sun provides enough energy to do much of the job.

In sunny, temperate climes, the Sun can provide three-quarters of the heating and cooling needs of a 1,500-square-foot home using 600-800 square feet of the roof for a collector surface. If solar heating and cooling were built into all new homes and single-story commercial buildings in the United States between now and 2000, the Sun would meet 4.5 percent of the country's overall energy needs. By the year 2020, it could be 8 percent. These are significant savings and, most important, enough technology exists already to begin using solar heating and cooling.

To do it we would have to revise our methods for constructing buildings. The roof of the typical American home could be adapted to an excellent energy collector, even though it is now built for the opposite purpose: to exclude solar radiation. What we need is a controllable roof operated by a sort of demon who lets heat in during cold weather and, when the days turn hot, directs the solar energy to an air-conditioner.

Mechanizing the demon

No demon, of course, is really needed, only an engine that uses solar heat to run an air-conditioner. There would also be pumps, valves, and a heat reservoir to ensure that roof-collected heat is available when and where it is needed and stored for later use when not needed. Solar heat could then be applied to both winter heating and summer cooling, as well as providing hot water (the primary energy user in much of California and several other States). A conventional auxiliary heater would be used when the Sun and stored heat can't provide enough energy, with the amount of auxiliary heat required depending on climate and weather.

This "solar system" generally has three components not found in the conventional "comfort package":

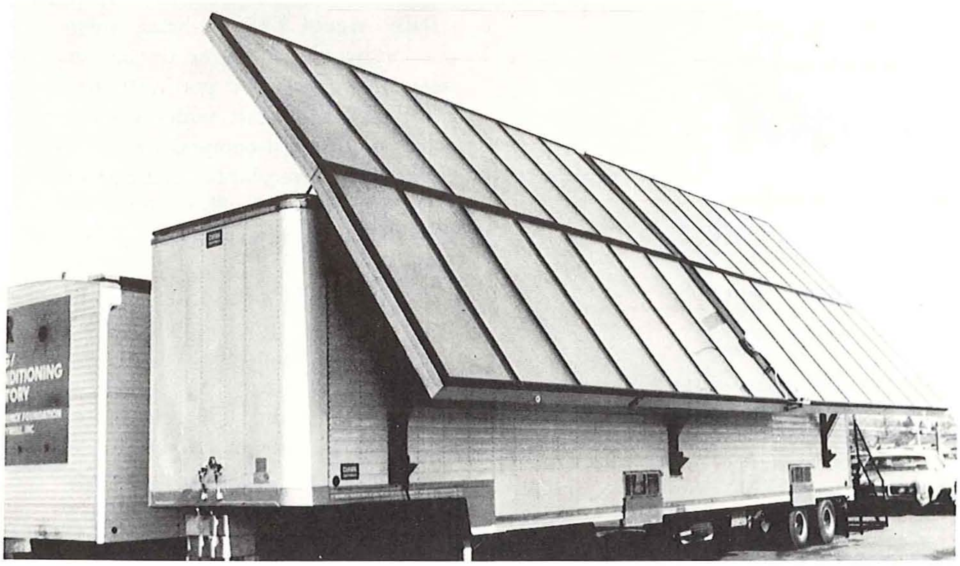
- A solar heat collector. This can be a heat-absorbing surface that transfers the heat to some fluid.
- A heat reservoir. This usually is a thermally insulated container in the basement filled with water or some other heat absorbers. A reservoir may not be needed if some other backup energy system is used.
- A heat-operated air-conditioner. Anyone who has seen a refrigerator running off natural gas knows that there is no contradiction here. Gas expansion and subsequent compression can cool. Absorption-type air-conditioners appear attractive for solar homes. (Under NSF grants groups at the University of Maryland, University of Florida, and Colorado State University are pursuing this prospect.) However, the air-conditioning part of the system needs research to help select and improve on the best schemes from the many that ha been suggested.

Even though solar air-conditioni technology lags heating technology a b it can now be applied to homes, schoo post offices, and other buildings on experimental basis.

Solar heating and cooling is a tec nology making the transition from t laboratory to practical reality. As Wor War II propelled electronics and TV in prominence, energy shortages may the same for solar power. There is, ho ever, an added element that should spe the process up even more: the potenti impact of innovation. Some good bas ideas could make solar energy, which already looking good, even more com petitive with other forms of energy.

Recognizing this, NSF is supporting wide range of research projects in "i novative technology," promising ide submitted by universities and industr Understandably, some of these projec won't achieve their goals, because inn vation can't be guaranteed; but othe ideas may turn out well enough to a celerate the conversion to solar heatin and cooling.

In addition to fostering inventio (with all its unforeseeable consequences NSF is also attempting to move sol heating and cooling technology toward an industrially based, commercially re



Calibrating the Sun. This transportable energy laboratory—with a companion solar-heated and -cooled "office" trailer—is collecting solar radiation and climatic data at different locales in the United States. The information will be valuable for designers of solar-heated and -cooled structures in the future.

warding enterprise. In three separate projects, TRW Systems, Westinghouse, and General Electric have begun systems studies that should lead to proof-of-concept experiments that will convert the nascent technology into hardware systems. These installations will then be evaluated in a real-world environment. In short, NSF wants to show that solar heating and cooling can be commercially viable. Eventually, NSF will turn this program over to mission-oriented Federal agencies, and it is expected that industry will ultimately find the business so rewarding that it will assume the burden completely.

But before that day arrives, solar power must be sold as a desirable and economical technology. Among those special problems to be dealt with:

- Does the solar home look "too different" for the buyer?
- What will the effect of the new look be on property values?
- Will solar home designs meet building codes?
- How about insurance coverage for all that glass on the roof?
- If millions of solar homes are built, what would be the impact on scarce raw materials?

The $135 billion building industry, home buyers, municipal governments, insurance companies, and a host of other interests await the answers. ●

SOLAR ENERGY

Heating and Cooling of Buildings: Step Right Up and Take a Look

Ideally, solar heated and cooled buildings should be built that way from the beginning. The two dozen or so solar homes that have been built to date have been experimental. All have been different, and none has been a complete system. Understandably, builders and buyers are reluctant to embrace such an uncertain technology. Confidence and a good data base are both wanting.

To create a more favorable climate for solar heating and cooling as quickly as possible, NSF has retrofitted four schools in various parts of the country with solar heating equipment. The advantages of this approach are several:

- Retrofitting can be completed in a couple of months.
- A great deal of new data can be garnered quickly for the design of new buildings.
- If successful, thousands of similar structures (shopping centers, warehouses, etc.) can be retrofitted quickly for a significant energy savings.
- The school projects are highly visible and will instill public confidence in the utility of solar energy.

The schools and contractors are:

Osseo, Minnesota; North View Junior High School	Honeywell, Inc.
South Boston, Massachusetts; Grover Cleveland Junior High School	General Electric Co.
Warrenton, Virginia; Fauquier County Public High School	InterTechnology Corp.
Baltimore, Maryland; Timonium Elementary School	Aircraft Armaments, Inc.

At two schools the collectors will be on the roofs; at the other two they will be on the ground nearby. The Sun won't supply all the heating needs, and the projects' emphasis is on amassing data (performance, reliability, costs) during the heating season.

Following the Sun

While the four retrofitted schools are geographically dispersed, they don't represent the whole spectrum of U.S. climatic conditions. NSF, therefore, has contracted with Honeywell, in Minneapolis, to build and operate a mobile solar laboratory to gather additional data and establish a reference base.

One of the two trailers that make up the mobile laboratory is filled with solar heating and cooling test equipment plus a comprehensive set of weather instrumentation. The second trailer is a mobile home, typical of the species except that it is heated and cooled by solar energy. (Hot water also comes from the Sun.) The heat is collected by 650 square feet of panels on the ground outside the trailers. In the winter Sun, water circulating at 11 gallons per minute can be heated to 130° to 140° F. Part of that heat keeps the trailers warm during the day and supplies the hot water; the rest is stored for nighttime use.

During the winter and early spring of 1974, the mobile laboratory has been taking operational data in different parts of the country with only the heating equipment installed. Later in the spring a lithium-bromide, absorption-type air-conditioner will be installed, and the laboratory will again make the rounds to test that portion of the equipment.

As the mobile laboratory tours the country, architects and building contractors will have the opportunity to see firsthand how solar heating and cooling systems work and how they can be applied to future construction. The second trailer, the "mobile home," thus serves a double purpose: mobile solar home and roving classroom.

A home is not a house

Popular as trailers are, they are not built like the houses and small commercial buildings where the main impact of solar heating and cooling will be felt. Trailers have no basements for heat storage and no slanted roofs for permanent solar collectors. True solar houses are needed to test heating and cooling equipment under year-round climatic conditions. With NSF support two solar houses—complete from basement to roof with no retrofitting—have been constructed.

Solar One, already completed at the University of Delaware, actually goes beyond the solar heating and cooling concept. Here, NSF supported the solar photovoltaic cells that are mounted on its roof to convert part of the sunlight into electricity. Solar One is heated in part from hot water produced by the roof-top collectors, but air-conditioning comes from conventional electric air-conditioners. Great pains were taken in the design of Solar One to make the most of incident sunlight. Its south-facing, steeply slanting roof sets it apart from suburbia's usual house, and its windows are rather narrow to permit better thermal insulation. The basement burgeons with plumbing and thermal storage machinery. Nevertheless, one is quickly and easily "at home" in the house.

The second solar house is being completed at Colorado State University, at Fort Collins. There, both heating and air-conditioning are powered by the Sun. Cooling will be provided by a lithium-bromide absorption-type air-conditioner previously tested at the University of Wisconsin. As usual, the collectors are roof-mounted, and water is the heat transfer fluid. The overall objective of this project is to design, build, and test a reliable, economical, integrated solar heating and cooling system. After final performance testing, NSF plans to use the house for testing components and systems being developed by other grantees and commercial manufacturers. ●

SOLAR ENERGY

Photovoltaics: Photons In/ Electrons Out

Converting sunlight into a stream of electrons coursing through wires in a power grid usually involves heat—a heat engine to be more specific. Even wind power depends upon differential solar heating of the atmosphere. Photovoltaic cells are the sole exception. It's not that heat is bad or heat engines crude; it's merely that the solar-thermal route doesn't exploit the unique bond-breaking capabilities of the solar photons. Photovoltaic cells are neat, clean, and cold; a magic box—photons in, electrons out.

Manifestly, there would be no fossil-fuel or nuclear powerplants under construction if these were the only considerations. Unfortunately, solar cells cost on the order of $50 per watt, approximately 100 times the cost of a coal-fired generating plant. It comes as no surprise that almost all of NSF's photovoltaic programs are aimed at cost reduction. (See "New Watts Under the Sun" in *Mosaic*, Fall 1973, for a more comprehensive article on photovoltaic power.)

The Czochralskian dilemma

The common silicon solar cell is made from an artificially grown crystal. The basic technique for growing such crystals was developed in 1923 by an inventor named Czochralski. The Czochralski method of "pulling" a crystal from a silicon melt is tedious and expensive; it's a batch-type process requiring highly skilled workers. Furthermore, each crystal wafer must be laboriously cut and ground to shape, put through chemical diffusion operations, and finally electrically connected and mounted to create large arrays. There must be a better way.

NSF would like to bring solar
costs down by a factor of 100 in
years—to about 50¢ per watt, or $.
per installed kilowatt, which would m
them almost cost-competitive with c
temporary powerplants. Some promis
ideas for cheaper cell manufacture
now being pursued with NSF supp
such as:

- Pull single crystals of silicon c
tinuously from a melt. (Harva
Tyco Laboratories)
- Manufacture polycrystalline silic
cells in thin-film form on a c
tinuous basis. (Boston Colle
Southern Methodist Universi
Texas Instruments)
- Explore other materials that mi
be cheaper to fabricate, such
CdS/Cu_2S thin-film cells based
Cu_2S and ternary compounds, me
oxides, GaAs, and other III-IV co
pounds. (Brown University, U
versity of Delaware)
- Investigate Schottky Barrier pho
voltaic diodes and heterojuncti
solar cells based on II-IV co
pounds. (Stanford Universi
Rutger University)
- Cut cell area required with so
flux concentrators. (Arizona St
University/Heliotek)
- Convert solar energy photochen
cally via photogalvanic cells or u
the photo-formation of fuels
cheaper ways to utilize solar fl
(Boston University)

The specialty market

Soon after photovoltaic cells were i
vented at Bell Laboratories in the 1950
small arrays of them were mount
atop telephone poles for booster pow
This experiment didn't prove econom
cally competitive with other sources
power, but it typified the role played
solar cells over the past two decades-
that of small, remote, specialty pow
sources. The premier example, spac
craft, has consumed hundreds of kil
watts of solar cells at prices arou
$1,000 per watt. But, obviously, sol
cells have no competition in space, eve
at that price.

Now that some manufacturers a
offering cells at $50 per watt and les
some remote terrestrial application
such as harbor buoys and fire looko
radio telephones, become attractive. Th
specialty market is growing, but it
insignificant compared to residential an
commercial needs for electricity. B

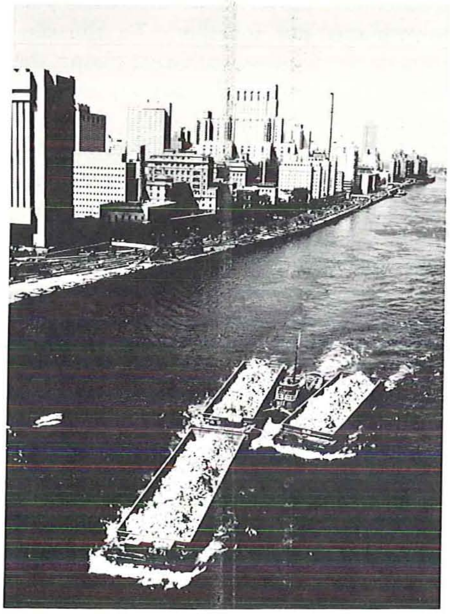
because photovoltaic cells have always been relegated to these specialty markets by economics, many power company managers discount their future in larger markets. "Once a toy, always a toy."

So even if NSF programs should reduce solar cell costs to a competitive 50¢ per watt, there will still be an uphill task of persuasion. In current parlance, this is an "institutional" problem. Solar cells must not only be cheap but they must be introduced in ways that don't violently perturb the present electric power infrastructure. The transition must be smooth.

Some power companies are already backing solar power financially, in a small way, of course. Solar One, the solar house at the University of Delaware, is supported by the Delmarva Power and Light Company and other institutions. Workers on this project see the next logical step for photovoltaic electricity as the application in schools, shopping centers, and small aggregations of buildings where power requirements are between 10 and 1,000 kilowatts of electricity. NSF hopes to have powerplants of this size in operation by 1982.

The next higher level of integration would be commercial and industrial complexes requiring about 10 megawatts. Central station plants in the 100-megawatt class would be last and could not be expected to be operational before 1990. ●

Garbage to gas. Research being done now may enable municipalities to economically convert large portions of their organic wastes to clean, burnable methane gas.



SOLAR ENERGY

Bioconversion: Energy Farming and Recycling Wastes for Power

For 80 million years the coal swamps grew, and died, and grew, and died, and built up rich layers of hydrocarbons manufactured by cycads and palm-like trees under the driving Sun.

For another 340 million years, after sediments covered the brown debris, Earth pressures squeezed the swamp crop dry and condensed it into the black energy we call coal.

There is nothing in the coal that wasn't in the swamp plants, so why not, in our present need, short circuit those 340 million years of geology, grow our own crops, and treat them as if they were a kind of low grade, unfinished coal? The essential hydrocarbons are present in today's cattails as surely as in the Carboniferous cycads, and a variety of laboratory processes can convert them into familiar fuel forms. The catch, of course, is that the geologic processes we're bypassing concentrated the materials, raising their energy value.

So the foremost problem we face is to collect enough biomass, cheaply enough, to be economically competitive with other energy sources. If we can, then we may someday see "energy plantations" where solar radiation, instead of heating water or activating photovoltaic cells, would simply do what it has for eons: make plants grow. We then could harvest those plants for possible use in four different ways:

- Although it seems archaic, it may be economical to grow trees, cut them down, convert them to chips, and use them as fuel for a powerplant.
- Through a quiet process of fermentation, slurries of organic materia can be converted to methane g (natural gas) and various usef chemicals, including animal fee stocks.
- At high temperatures and pre sures, slurries of organic materia can be converted to a burnable oi
- Dried materials can be converted t burnable oil and char at high temperatures in the absence of oxyge

Energy plantation

At the Stanford Research Institute group headed by R. E. Inman is invest gating the "energy plantation" concep a combination of agriculture and chemical engineering. There are plenty o questions and problems to be dealt wit Where, for example, should the plantation be located to receive maximum sur light? If you start looking in the cloud less but arid Southwest, how are you go ing to water the plants? You can assur the availability of Sun and water b turning to kelps and algae in the ocean or lakes, but their high water conter reduces yields.

Which plants would be most efficien in creating a mass of foliage? Whic foliage would be most efficient in creating energy? What about susceptibilit to pests?

Plants grow more efficiently in an at mosphere enriched with carbon dioxide their primary raw material. A plasti canopy would increase the CO_2; is i worth the expense? Perhaps it could b harvested and used along with th plants; would that change the economi picture?

After the site selection, watering, feeding, atmosphere augmentation, and what ever else is necessary, would it be bette in the end to burn this "low grade coal" for its direct heat energy or to convert i into methane or low Btu gas?

Answers to these questions are emerging:

- Theoretical calculations and fiel measurements show that the plant with the best potential as biomas producers seem to be sugarcane sunflower, the sorghums, Sudan grass, the eucalypts, water hyacint and fresh-water algae.
- Water, essential to plant growt turns into a negative quality whe you try to get the energy ou particularly by burning. Som otherwise efficient biomass pro

ducers (the algaes and water hyacinth) are 95 to 98 percent water by weight; certain woods, on the other hand, are only 30 to 35 percent water.

- Other plants, such as the pines, hold burnable resins, which give them a higher Btu content than, say, the deciduous trees. Oil-bearing herbaceous tissues, including the stems, leaves, and seeds of oil-bearing plants (sunflower, safflower, cotton) hold more energy than non-oily grasses.

The SRI team is trying to determine, within these and other conditions (such as the location of the energy plantation in relation to the energy consumer, costs of land, necessity of cultivation or other agricultural practices) at what points in the energy cycle, in what places in the country or near it, biomass farming might make a significant contribution.

Garbage In/Gas Out

But closer to home there already exist great quantities of what might be considered harvested, collected, and partly digested biomass—the organic portion of the cities' trash, garbage, and sewage. This solid waste is already giving fits to municipal managers as they try to decide what to do with it without polluting the air by burning, killing the rivers by dumping, or fighting the politicians of the nearby countryside for a place to bury it.

Two major investigations with NSF support are under way, one on the east coast, one in the Midwest; other allied work is being supported by the Environmental Protection Agency. EPA is chiefly interested in the diminution of the waste, while NSF concentrates on the production of clean-burning methane gas.

In Cambridge, Massachusetts, Dynatech R/D Company, after two years of laboratory experimentation with methane production from solid waste, believes it has proved the feasibility of its method. It is now moving toward design of a "proof-of-concept" plant that could handle several tons of municipal waste each day, according to Donald Wise, the principal investigator.

The heart of the Dynatech process, like the others, is the use of bacteria, in the absence of oxygen, to convert the solid waste (predominately cellulose) to methane and carbon dioxide.

The chemistry in simplified form runs:

$$C_6H_{10}O_5 + H_2O \rightarrow 3\ CO_2 + 3\ CH_4$$

Under these circumstances, a pound of waste will yield approximately 6 cubic feet of methane at standard temperature and pressure.

Dynatech's figures show 182 million tons of solid waste currently available each year in the United States. Conservatively, half of this, by weight, is organic material suitable to conversion, which could add 1.2 trillion cubic feet of methane—six percent of the present demand for fuel gas.

The economics of the process are not yet such as to put it in competition with natural gas. The solid waste gas, Dynatech claims, could run between one and two dollars per thousand cubic feet, considerably more than present costs of natural gas (which vary because of many factors, particularly distance from the wellhead). But as for other new energy technologies, the differences may narrow if costs for existing fuel gas rise and those for manufactured gas, perhaps, fall.

Also, the researchers point out, the costs normally involved in disposing of that part of the solid waste that would be gasified should be subtracted from the final price—a trash disposal credit. This situation is particularly attractive to political divisions that happen to be in both the solid waste disposal and the gas marketing business. For example, Holyoke, Massachusetts, population 50,000, is one that could convert its own solid waste to a third of a billion cubic feet of pipeline gas—13 percent of the area's usage.

If, in addition to this, municipal liquid waste—sewage—could be added to the solid waste, the yield of burnable gas would increase, the sewage problem would decrease, and the continuous reinoculation of the mix with fresh anaerobic bacteria would help keep the reaction going. The solid organic material in the sewage—the sludge—although enough to have caused considerable town-country bickering over its disposal, is not by itself enough, Dynatech figures, to rival solid waste as a methane producer.

A second research group, under the direction of John Pfeffer at the University of Illinois, is building a continuously operating experimental system (having a capacity of 50 pounds of municipal refuse an hour) to demonstrate the viability of its system, which also relies on the ability of anaerobic bacteria to produce methane from cellulose and other organic waste. Terming the results their laboratory-scale operations thus f encouraging, the Illinois group corrob rates Dynatech's estimates that if urban solid wastes were converted, t Nation's available fuel gas would be i creased by six percent. Essential to t Illinois work is the concurrent develo ment of a mathematical simulation the system. Using both, the scientis expect to be able to predict the be combination of process variables f producing methane at the lowest co under widely varying conditions. ●

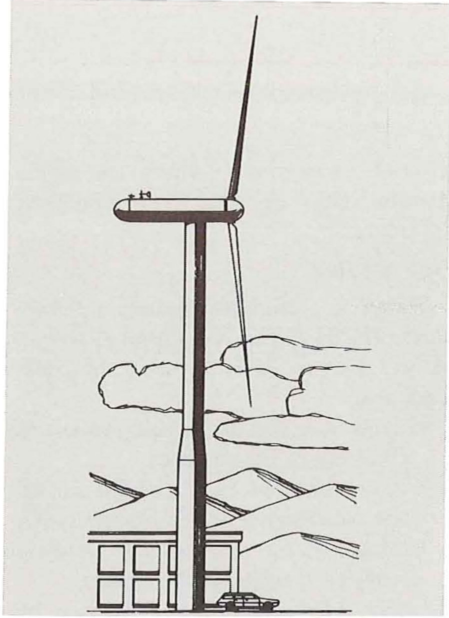
SOLAR ENERGY

Windpower: A Ne Look at an Old Draft

The great weather systems tha wheel across our continent ar actually Sun-driven atmospheri machines—machines that generate many times more power than all fossil fue powerplants put together. To the pioneers on the wind-swept Great Plains, the windmills that tapped these air currents substituted for the mill races they had left behind in the East. Between 1880 and 1930, over six million windmills pumped water, sawed wood, and generated electric power in the American west. A few windmills remain today, but more for nostalgia than power; the rural electrification programs of the 1930's made them obsolete.

But history has a way of coming back to yesterday's obsolescence. Some power engineers now foresee windpower generators once more strung across the Plains, perhaps numbering in the thousands, replacing or augmenting fossil fuel powerplants. Others speculate on festoons of windmills anchored just out of sight of the U.S. east coast, taking advantage of dependable offshore winds. The picturesque prairie windmills won't return; but in their stead will be large-scale, sleek, new wind generators built from modern materials, serving the national power grid rather than isolated homesteads.

Abundant windpower is there for the taking. It has been estimated that practical wind-driven powerplants could generate as much as one trillion kilowatt-hours annually—more than half of the U.S. annual consumption. This energy resource wasn't economical as long as fossil fuels were cheap. Now that the picture has changed, windpower's future depends on the progress made in several technical areas as compared to the successes registered by competing types of powerplants.



Windmill of the 1970's. This experimental wind turbine generator, to be built in 1975 on the shores of Lake Erie, will generate 100 kilowatts of electricity in an 18-mile-per-hour wind.

The wind's whims

On some parts of the Great Plains the wind seems incessant, but it's not really so constant; it veers and gusts and may disappear for days on end. More than any kind of power generation technique, windpower is dogged by inconstancy. The power output varies far more than the wind input. A wind that increased from eight mph to ten mph would double the power output; a comparable two-mph decrease would reduce the output to less than half.

If that gusty wind is driving a conventional alternating current generator, the frequency of the current, which is related to shaft speed, will fluctuate wildly along with the power level. For an electrical power grid finely tuned to 60 cycles, such frequency transients are intolerable. One solution is to feed the frequency-varying power into a load that is insensitive to frequency; for example, a rectifier to convert it to direct current for the generation of hydrogen fuel. Another possibility is the use of an alternating current generator with an output frequency that is independent of shaft speed. Under NSF sponsorship, engineers at Oklahoma State University, Stillwater, are investigating a field-modulated generator operating on a "frequency down-converting" principle that achieves this objective. Ten-kilowatt experimental units have been built that are smaller and lighter than conventional generators of the same power rating.

The variability of the wind also makes it hard to know just how much power can be generated at a particular site and what kind of equipment will be most efficient. To build an effective, reliable powerplant, the wind's velocity must be known as a function of time and, for a few hundred feet, altitude. (Ground winds are more variable than those a few hundred feet up.) Engineers must know much more about wind behavior than the kinds of average velocity figures now measured at weather stations and airports. One of NSF's priority efforts is therefore to establish a sound data base to aid the design of wind turbines and help in site selection.

In the Greek myth, the escape of the winds from the bag they were supposed to be contained in, like the opening of Pandora's Box, turned out badly. Would taming the winds have similar unhappy consequences? While not considered likely, would extensive systems of windmills affect the local or the large-scale climate? Who, in fact, owns the wind? Is it like water, to be apportioned to people along its path? Inadvertent weather modification from various activities, though it would seem generally to be inconsequential, is extremely difficult to prove or disprove. Lawsuits are easily brought, and decided only with difficulty. For that reason, NSF's windpower program will include the study of these environmental and legal ramifications.

A railroad to nowhere and sails in the sunset

Windmills are not the only wind-driven machines. Sails have pushed ships for millennia. In fact, modernized, four-masted clipper ships now being designed in West Germany would use only five percent as much fuel as conventiona ships. A group at Montana State University at Bozeman is looking at a way to generate power using sails or airfoils mounted on a string of what might look like railroad cars on an oblong track. With the angle between the wind and the airfoil controlled automatically, motive power could be extracted from the wind on all portions of the track with the possibility of much less land used than would be used by conventional windmills. Generators attached to the car wheels could send electricity to a third rail and thence to a power grid or power storage facility.

A group at Princeton University is examining the "Sailwing" concept, which is a descendant of the ship's sail by way of glider research. The use of a stiff metal leading edge and flexible material for the rotor blade itself might not only lead to lower cost rotor blade, but judicious combinations of stiffness, mass, and aerodynamic properties could bypass complex variable pitch control systems.

Wind turbines and timetables

Windpower demands no major technological breakthroughs; it's the economic position that must be assessed and strengthened. Systems can be built almost immediately. NSF is being assisted by NASA's Lewis Research Center in building a 100-kilowatt experimental wind turbine generator on the windy shores of Lake Erie. The emphasis in this project is on determining the cost-performance relationships, because even though the wind is "free" the capital cost per installed kilowatt is much higher for windpower plants than for equivalent fossil-fuel stations.

This spring, a proposal request will be issued for the design study of a wind-power plant in the one-megawatt range, with construction and testing of such a system scheduled for 1976. These will be the largest experimental systems constructed in this country since the one-megawatt Smith-Putnam machine built in Vermont in 1940. NSF's target for the end of the 1970's is an economically sound proof-of-concept experimental 10-megawatt system and the associated and necessary scientific and technological bases. The timetable is obviously much shorter than those for other types of solar powerplants, reflecting perhaps the fact that wind was man's first practical power source after fire, and he already knows how to use it. ●

SOLAR ENERGY

Ocean/Thermal: An Unmixed Blessing

By far, the largest solar collector is the sea's surface. Tropical surface waters are a tepid 82° to 85° F, and they are separated by as little as 2,000 feet from a practically inexhaustible cold water reservoir at 35° to 38° F. These dense, near-freezing waters have traveled from the polar regions where they slide under the warm, buoyant surface waters moving poleward. The different densities keep the layers separated—to our advantage, for even with two-percent-efficient heat engines, the Gulf Stream alone could provide 75 times the energy needs of the United States. The French physicist Jacques D'Arsonval predicted in 1881 that we would one day extract our power from ocean thermal differences rather than fossil fuels. After we have dallied for a century with fossil fuels, D'Arsonval may be borne out.

The global oceanic circulation systems are so ponderous that diurnal and annual variations in the Sun's heat input are almost completely smoothed out. In marked contrast to windpower and solar powerplants employing artificial collectors, the ocean thermal difference is a constant source of energy. Thermal energy storage is not necessary because the ocean itself is the storage reservoir. Consequently, some ocean thermal powerplants could be "base load" plants. The concept depends upon whether realistic energy conversion equipment can operate on the small temperature difference of 30° to 50° F. This is roughly the temperature difference between the inside and outside of a home refrigerator and a far cry from coal- or oil-fired powerplants which commonly operate with an 800° F temperature difference.

Pipe dreams

Piping is a routine engineering problem in the design of conventional powerplants. Not so here. Among the problems are:

- How can the deep, cold waters be brought to the surface?
- Can sufficient heat transfer surface be constructed at reasonable cost?
- How can electric power or artificial fuel be transported to shore?

Because the temperature difference between hot and cold reservoirs is so small, the theoretical efficiency is only about six or seven percent, and the practical efficiencies even lower. Colossal volumes of water must be moved for a powerplant in the 400-megawatt class. For each kilowatt of useful power generated, about 30 kilowatts of heat must be transferred to the cool water being pulled up from the depths. To do this, large areas of heat exchanger surfaces seem to be needed, although design improvements may produce reductions in the areas required.

Pipes would be a plumber's nightmare were it not for some redeeming features of the ocean thermal difference approach:

- Temperatures are low and materials consequently tractable
- Pressure differences across heat exchange pipes can be made negligible by submerging the heat exchanger
- Large structures, such as the 2,000-foot suction pipe, can be made essentially weightless by adding buoyancy.

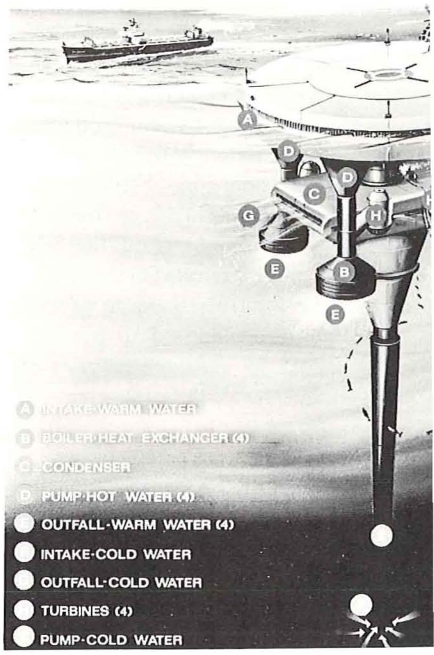
The submergence of most of the powerplant is an important feature of modern designs. The two major experimental plants built in the past had to fight the vicissitudes of the ocean surface. (The small plant built by Georges Claude in Cuba in the 1920's was shore-based; the French attempt off the Ivory Coast in the 1950's envisioned a floating structure.) In fact, damage by waves and currents, particularly to the cold water suction pipe, complicated these exploratory ventures.

A submerged catamaran

Another limiting factor in Georges Claude's Cuban venture was his choice of seawater as the working fluid. For large plants, seawater's very low vapor pressure would lead to enormous turbines and associated equipment. Mos modern concepts focus instead upo Freon, propane, or ammonia, which lea to more compact, efficient powerplant but require large amounts of heat to b exchanged. Nevertheless, Claude di generate 22 kilowatts of electricity an did pioneering work that we can buil on today. NSF has contracted wit the University of Massachusetts an Carnegie-Mellon University to take u where Claude and the French left off

A crucial engineering decision mad by the Massachusetts group was to g beneath the surface with a submarin powerplant. The major features of thei 400-megawatt concept are:

- A moored pair of neutrally buoyan submarine hulls is built in a catamaran arrangement. Each hull i 100 feet in diameter, 600 feet long and built of reinforced concrete 2 feet thick.
- Two sail-like evaporators are exposed broadside to the warm wate current of about two and a hal knots.



Maripower. This artist's concept shows a largely submerged ocean-thermal powerplant that would operate on the temperature differences between warm surface water and frigid deep water.

- A single cold water suction pipe, with a diameter of about 80 feet and a length of almost 1,100 feet, projects into the current at an angle. Pumps augmenting the force of the current will bring up about 30 million gallons per minute.
- A propane cycle is used, with turbo-machinery inside the concrete hulls.
- The hulls also contain electrolyzers to convert the electricity into hydrogen fuel.

No one pretends that this concept is more than an idea that has been roughly sized according to thermodynamic and engineering requirements and the constraints of existence a few hundred feet below the Gulf Stream surface. But at least we have a preliminary picture of what such a plant might look like.

Oasis in the ocean

Proponents of ocean thermal difference powerplants never fail to point out that the immense structures they hope to build in the sea will be floating islands with abundant supplies of two precious commodities: energy and cold, nutrient-laden water.

The water, of course, is the same kind that upwells naturally in a few favored regions of the world where fisheries flourish (see "The Sea Turns Over" in *Mosaic*, Winter 1974). Cold water brought to the surface artificially may also create regions of high biological productivity. Fisheries and mariculture may flourish around ocean thermal difference plants, producing shellfish and other forms of protein.

Freshwater for export to the mainland could be another byproduct; there's plenty of water and plenty of energy to desalt it. Or, the cold water from the depths could be used to condense moisture from the humid air, as has been proposed for some tropical islands.

The concept of solar seapower is obviously still in the visionary stage. A major NSF goal is to establish that the concept makes engineering and economic sense. With windpower one can talk of megawatt demonstration plants within five years; with ocean thermal difference plants, a realistic five-year goal is a proof-of-concept experiment. The ocean, however, has far greater potential, for it exceeds the atmosphere by several orders of magnitude as a reservoir of stored solar energy. ●

SOLAR ENERGY

Storage: Making H While the Sun Shines

Solar-thermal powerplants, photovoltaic powerplants, and wind powerplants are all fundamentally different from fossil-fuel electric powerplants. The direct solar units can operate only during clear weather and daylight hours, and the wind units only when breezes blow. All are restricted—for optimum output—to special locations, frequently great distances from major U.S. population centers which, of course, also want abundant power after sunset.

Aerospace Corporation, under an NSF contract, has been studying where solar-thermal powerplants fit into the U.S. power picture from two standpoints:

- How well can they be integrated into existing power grids?
- How well do they mesh with extant institutions?

While Aerospace's concern has been specifically for solar-thermal plants, some of their findings are applicable as well to other intermittant solar power sources. One clear discovery has been that solar power cannot contribute more than about 20 percent of the country's total electric requirement unless new ways are found to store energy.

The reasoning goes like this: Almost 75 percent of the U.S. electrical power consumption falls in the "base-load" category; that is, it is needed all the time, night and day, in sunny and cloudy weather. Solar power cannot provide the base load without a way to store the energy it generates during the day. Most of the other 25 percent of U.S. power need is of the load-following or "intermediate" type, which can reasonably be provided by solar plants. This type of service should be the goal of the first solar powerplants.

A Bag of Winds

But solar electricity need not be limited to serving that fifth of our electrical needs. In Greek mythology, the Earth's winds were loosed from a "bag." Windpower and solar power engineers could use some bags today—something to store energy for release when doldrums appeared. NSF grantees are investigating several kinds of "bags."

At the level of an individual home, storage batteries are an expensive but reasonable solution. They become prohibitively expensive at higher power levels, and pumped hydroelectric storage—where water is pumped to a high reservoir during periods of excess power production, then released to generate electricity when demand is greater—could be used in hilly or mountainous areas. For short-period variations in wind power, a high-speed flywheel can store a surprising amount of energy; more than batteries of the same weight.

But chemical storage may be the most important in the long run. Instead of connecting solar power to an electric grid, the power could be funneled to electrolytic cells to generate hydrogen, a promising substitute for "spirits of petroleum" as they called gasoline around the turn of the century. Solar powerplants then become fuel manufacturing facilities rather than on-line central power stations.

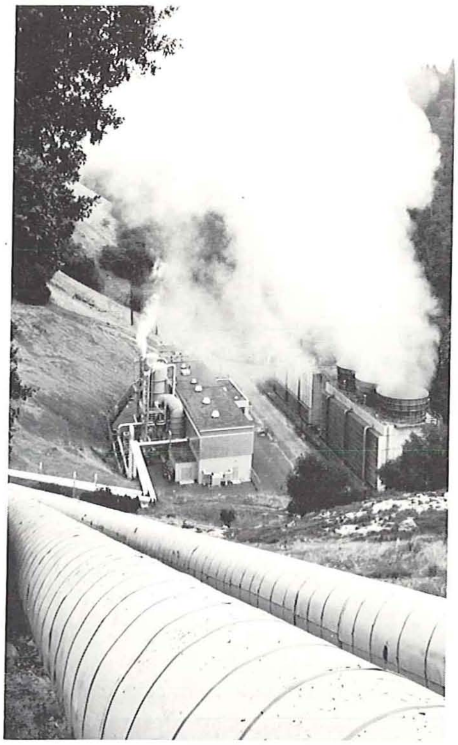
The well-publicized vision of a hydrogen fuel economy fits well with solar power. Whenever and wherever the Sun shines, solar cells and solar-thermal plants can manufacture hydrogen gas. Where the wind blows and warm ocean currents flow, wind and ocean-thermal-difference plants can also stockpile hydrogen. The hydrogen (or some other fuel) is, of course, merely a form of energy storage, but it is a form that can be transported and stored for use as a source of heat and electricity in vehicles, homes, and factories—in a sense, a "fossil fuel" a few days or weeks old instead of eons. With solar power and a hydrogen economy, the need for huge, interconnected power grids might well disappear. Little wonder that solar power enthusiasts worry about institutional problems, for solar power could and likely will revolutionize the way in which electrical power is generated, transported, and used. ●

GEOTHERMAL ENERGY

Taking Mother Earth's Temperature

The Earth was born hot and has been cooling ever since. As it cools, heat moves outward from the core. Heat is also generated in the crust as radioactive elements such as thorium and uranium decay, and by friction from tidal forces raised by the Sun and Moon. This heat, a legacy of primordial Earth, constitutes a huge, but still largely unknown energy resource.

Some of its manifestations—where steam or hot water reaches the surface unaided—are already exploited for some local heating and electric power generation. But potentially usable geothermal resources appear to be far more ubiquitous than those few well-known areas. One of the best prospects so far is in the mountains near Marysville, Montana, where an area of about 12 square miles located within 6,000 feet of the surface may be as hot as 800° F.



Geyserpower. Units 1 and 2 of Pacific Gas and Electric Company's dry steam power generation facility in Northern California have been delivering 24 megawatts since the early 1960's. The highest geothermal energy potential, however, is in hot dry rock systems, for which technology still must be developed.

In light of the apparently vast size of the Nation's geothermal resource and the fact that its exploitation should be relatively pollution-free, it's not surprising to see wide interest in developing it for energy needs. Leasing of 55 million acres of Federal lands in the West under the Geothermal Steam Act of 1970 got under way in late 1973, but that hardly assures development of the resources. The uncertainty associated with the development of hot dry rock energy is so risky financially that private firms are unlikely to pursue it. Still, the energy resource is there and may, with the benefit of a careful research and development effort, becor
economical.

For that reason a number of Feder
agencies, including NSF as lead agenc
are trying to remove some of the unce
tainties blocking development of ge
thermal energy.

Current drilling techniques rea
about five miles in conveniently so
sedimentary basins, so for the prese
we can tap geothermal energy only to
depth of about six miles at most. Withi
that six-mile layer most of the heat
so diffuse that the immediate futu
holds little promise for profitable extra
tion. But in some places, like Marysvill
there are "hot spots" where molten ro
has seeped close to the surface throug
faults in the crust. In general, the h
spots occur in zones of earthquake an
volcanic activity, which include muc
of the western part of the United State
Alaska, and Hawaii.

Four kinds of hot

There are four major types of ge
thermal resources—dry steam, we
steam, hot dry rock, and geopressurize
zones. Only the smallest, dry stea
is relatively well understood and ex
ploited. It occurs when hot water boil
in an underground reservoir. The stea
rises, some of it condenses on the sur
rounding rock, and dry steam approache
the surface so that it can be tapped an
used in a turbine. Electric generatin
stations using geothermal steam nee
no boiler, nor do they have the compli
cations that come with fuel handlin
and combustion. Not surprisingly, the
cost less to build and operate than othe
types of thermal powerplants.

But drilling has revealed only thre
areas in the world with commercial dr
steam resources, and their capacity i

limited. Starting 70 years ago dry steam has been tapped at Larderello, Italy, south of Florence, to generate electricity presently at a rate of 358 megawatts. Since 1960, the Pacific Gas and Electric Co. has been generating electricity from the world's largest dry steam field in the Geysers, 80 miles north of San Francisco. Their geothermal capacity is now about 400 megawatts, and plans call for a capacity of 700 megawatts by 1976, enough to fill the power needs of a city the size of San Francisco. The third commercial unit, in Japan, is only about 30 megawatts. Two other fields in the Monte Amiata region of Italy are producing now. Although more fields might be uncovered if exploration were stepped up, dry steam resources are probably too rare to have much further impact on the future of geothermal energy.

Wet steam is more abundant—perhaps 20 times as much as dry steam. Water is heated by surrounding rock to well above its normal boiling point, but remains liquid because of the high pressures underground. When the reservoir is tapped, the superheated water in many wells flows to the surface. The pressure drops, and a mixture of steam (about 10 to 20 percent) and water is produced. The world's best example of this is the hot springs and geysers at Yellowstone. Power production is more complicated than for dry steam systems because the steam must be separated from the water before it can drive the turbine.

Despite wet steam's relative abundance, few fields are used to produce electricity. Two in New Zealand and one in Mexico generate a total of 235 megawatts, with an additional 300 megawatts planned. These deposits are hot—640° to 700° F—but most wet steam deposits are at much lower temperatures. In this case the heat must be transferred to a lower boiling point fluid such as Freon or isobutane, which then drives the turbine.

An interesting advantage of a geothermal plant over conventional or nuclear plants is that the economics permit it to start small and add generating units as the reservoir is developed or as demand increases. So wet steam resources appear particularly promising for development of small (10 to 25 megawatts) plants in rural areas of the West. Geothermal resources, if found, could be significant at local or regional levels in the Pacific Northwest, for example, which has traditionally relied on hydroelectric power but now has no low cost sites remaining and no appreciable reserves of fossil fuels.

Geothermal resources producing wet and dry steam often signal their presence with hot springs or fumaroles at the surface of the Earth. Not so with hot dry rock systems, which may be the Nation's largest and most widely distributed source of geothermal energy.

Developing those resources is even harder, requiring drilling a hole and cracking the deep rock, either hydraulically as in conventional oil field development or by explosives. Water would then be injected into the fractured rock; after being heated to nearly the temperature of the surrounding rock, the hot water would be withdrawn through another hole. The heat would be extracted at the surface and the water reinjected into the underground system. The potential energy in the hot rock deposits in the Western States is huge, one estimate being the equivalent of the country's coal reserves, or approximately 300 Q (a Q is one quadrillion Btu's). But although much of the extractive technology needed may exist, it has never been put into use.

Hot spot. One of the most promising places for development of hot dry rock energy extraction is here at Marysville, Montana, where heat flow ten times the normal average has been measured.

The fourth form of geothermal energy, and perhaps the least understood, is geopressurized zones. In the deep sedimentary deposits of the gulf coast, heat, water, and natural gas are trapped between impermeable shale beds. Pressure in these formations are unusually high so geopressurized zones have thre sources of energy—the intrinsic heat the mechanical energy from the hig pressures, and the natural gas.

Petroleum exploration has uncovere numerous geopressurized reservoirs They can be found in a belt extendin 750 miles along the gulf coast from th Rio Grande to the Mississippi Sound Temperatures of 320° F to 555°F hav been measured at depths of 2.5 to 4. miles. But while geopressurized zone seem to have high potential as energ sources, so little is known about them that major questions must be answere about how to utilize them. One question is whether the reservoirs are large enough to warrant construction of a powerplant. Drilling is very expensive (reservoirs are typically deeper than two miles, compared to one mile or less for hot water resources), and no one knows whether the high pressure in one of these reservoirs will last very long.

An important first step in developing the Nation's geothermal resources is to find out how much there is. The U.S. Geological Survey has classified 1.8 million acres of land in the Western States (primarily California, Nevada, Oregon, and Utah) as being "known geothermal resources areas"; an additional 96 million acres have "prospective value." But within these areas, little is known of where the resources are located, the amounts of their energy reserves, in what forms, and what the economic life of reservoirs may be. ●

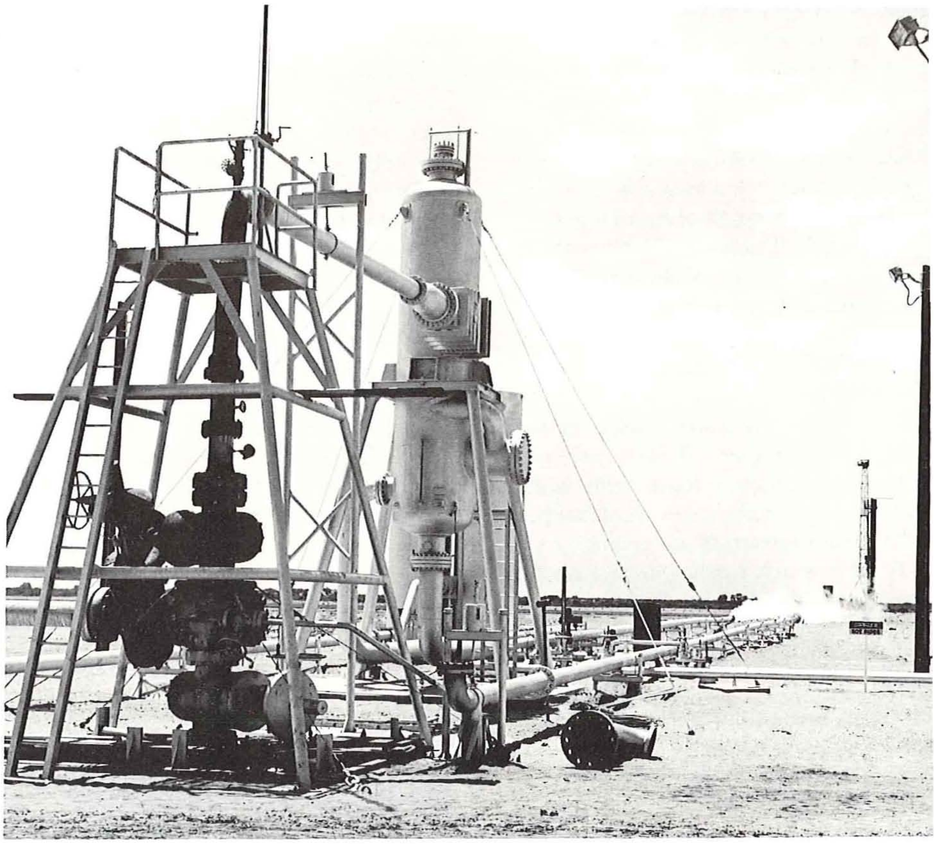
GEOTHERMAL ENERGY

Starting to Tap the Hot Reservoirs

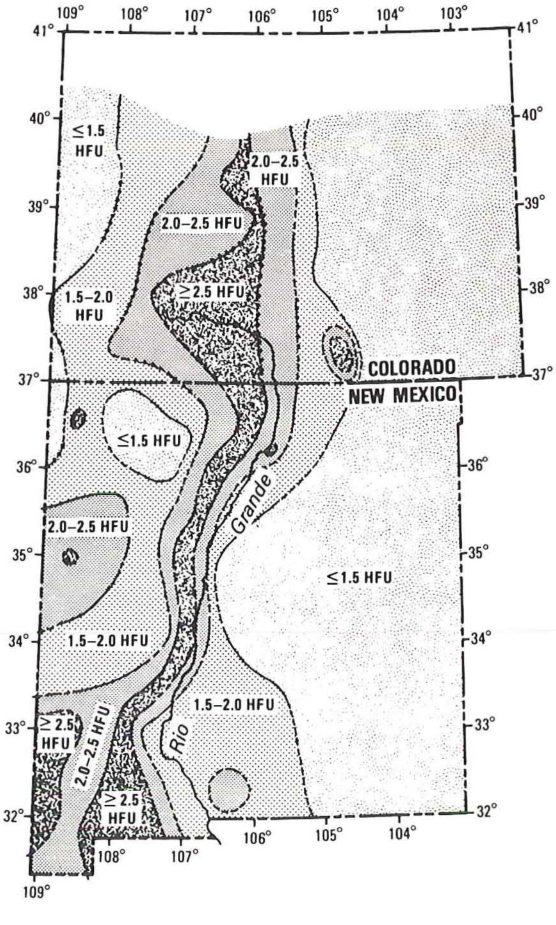
One of the fastest ways to explore for geothermal resources is to build on subsurface data already available. For example, Marshal Reiter and his colleagues at the New Mexico Institute of Mining and Technology found a potential geothermal zone running the length of the Rio Grande depression on its west side by measuring heat flow in 174 wells previously drilled for other purposes.

Heat flow measurements were also the basis for discovery of the geothermal anomaly at Marysville. In 1969, David Blackwell of Southern Methodist University, as part of a basic geophysics study of the Idaho batholith, measured the highest temperature gradient yet known in the United States near the old Marysville gold mining district. Blackwell has since pinpointed a promising site for drilling a deep hole—which would be a two-foot well narrowing to about eight inches at 5,000 to 6,000 feet. Drilling of the hole, scheduled for the summer of 1974, should answer a lot of questions about how much energy lies beneath the surface at Marysville, how it is stored, and whether it can be extracted. If extraction appears feasible, the next step would be an experimental generating facility, which could eventually lead to commercial development.

Another geothermal project is under way in Hawaii, which has among the highest power costs in the Nation because it is totally dependent on imported fossil fuels. Organized by the University, State, and County of Hawaii, the project is presently focused on the



Geothermal water. The primary goal of this Bureau of Reclamati experiment in a wet steam field in California's Imperial Valley is production of badly needed additional water for the Colorad River system.



High flow. Some potential geothermal resources, like this one stretching through Colorado and New Mexico, can be identifie by measurements of heat flow in preexisting drill holes.

Island of Hawaii, youngest of the Hawaiian chain and still growing from activity of the Mauna Loa and Kilauea volcanoes, The project is looking not only at the geothermal resource but also at the legal, regulatory, environmental, and socioeconomic implications of development.

The first phase of the project, including infrared scanning via aircraft, electrical resistivity, and a number of other geophysical surveys and related analyses, is well under way. It draws on an earlier study of Kilauea by George Keller of the Colorado School of Mines, whose project drilled a 4,100-foot well in the central crater. Keller's work, which tended to substantiate predictions made earlier from electrical resistivity surveys carried out around the summit of Kilauea, provided information on subsurface temperature and water movement that will help assess the island's geothermal potential. The Kilauea site itself, in the Hawaii Volcanoes National Park, will not be developed.

By November 1974, sites outside the national park for drilling additional deep holes should have been selected. Although the primary purpose of such holes will be research in the nature of geothermal reservoirs in the vicinity of an active volcano, the sites will be selected so that the hole could be incorporated into a 10-megawatt experimental powerplant.

Experimental powerplants

The Marysville and Hawaii projects may lead to experimental power-generating facilities envisioned as part of the Federal geothermal program. The experimental plants are a crucial step. If successful, they'll provide tangible evidence to allay the fears of many, especially in industry, that geothermal energy is too unreliable and unknown a quantity to be of commercial significance. In addition, the plants and their associated reservoirs will be open to industry, providing an operational environment for testing new hardware and engineering techniques. Ideally, there will be a parade of engineers and technicians through the plants, working on their own projects, and returning to their companies with new experience in geothermal technology.

There are seven different geothermal resource types whose utilization can be tested with experimental plants. One of these will be the hot dry rock resources such as may be found at Marysville. The Atomic Energy Commission's Los Alamos Scientific Laboratory is drilling into hot rock in the Jemez Plateau in New Mexico to set up a circulation loop with an injection and extraction well; the Laboratory will experiment with the petroleum industry's hydrofracting technique, in which water is pumped down at high pressure into the impermeable rock, causing the rock to open in a large vertical crack. The project could lead to a 10-megawatt pilot plant.

At least three experimental plants will be needed to prove the utilization concepts required for hot brine systems involving fluids of high temperature/high salinity, high temperature/low salinity, and moderate temperature (which are also low salinity). Geopressurized zones need a plant. Still another one could be built to study areas of normal heat flow so that geothermal energy can become a reality not only in the Imperial Valley but, perhaps someday, also in any area.

Finally, a plant under consideration would explore the nonelectrical uses of geothermal energy. Lower temperature geothermal reservoirs, although not efficient for power production by conventional methods, have for years been used for heating purposes. Homes of most of the 60,000 residents of Reykjavik, Iceland—as well as many smaller outlying communities—are heated by geothermal hot water. The water is also used in Iceland to heat greenhouses, for drying, for domestic hot water, and for swimming pools. Hungary and Russia, which have immense reservoirs of low temperature water, are developing the use of hot water for househeating on a large scale. A few hundred homes in Klamath Falls, Oregon, and Boise, Idaho, are heated by hot water from wells—the ones in Boise since 1890. A New Zealand paper mill uses geothermal energy for process heat, while a hotel in that country has installed a geothermal heating and air conditioning system that uses water as the refrigerant and a solution of lithium bromide as the low temperature absorbing fluid.

The water from wet steam reservoirs could also be used to provide potable water and as a source of extractable minerals. Since most of those geothermal resources are west of the Rocky Mountains, they could provide water for arid regions in the West. The Department of the Interior's Bureau of Reclamation and Bureau of Mines are exploring these nonpower applications in studies in the Imperial Valley. ●

GEOTHERMAL ENERGY

Problems Beneath the Surface

Experimental powerplants will us the best technology available a the time. But, meanwhile, researc is needed to develop better technique for the longer term. Among the problem areas where NSF believes new research is required are:

- Drilling technology. The geothermal environment is much mor hostile than that for oil and gas since temperatures and pressure are higher at shallower depths Conventional rubber seals, valves, cements, muds, heat shields, and sound mufflers won't stand up. Improvements are needed now in current technology, and eventually entirely new drilling techniques will be required to make geothermal development more attractive economically.
- Reservoir engineering and management. Little is known about how geothermal aquifers behave over the long term under production conditions. The problems are akin to those of petroleum engineering, so American industry's experience should help ensure that the various types of geothermal reservoirs yield their full potential. Paul Kruger and Henry J. Ramey, Jr., of Stanford University are studying ways of stimulating geothermal aquifers by use of high energy explosives. Using laboratory models, they're looking at how hot water boils and moves through fractured rock formations and how the quality of steam might be affected.
- Extraction technology. Once the reservoir has been developed, the energy must get to the surface and be used efficiently. Materials problems will arise in pumping out—

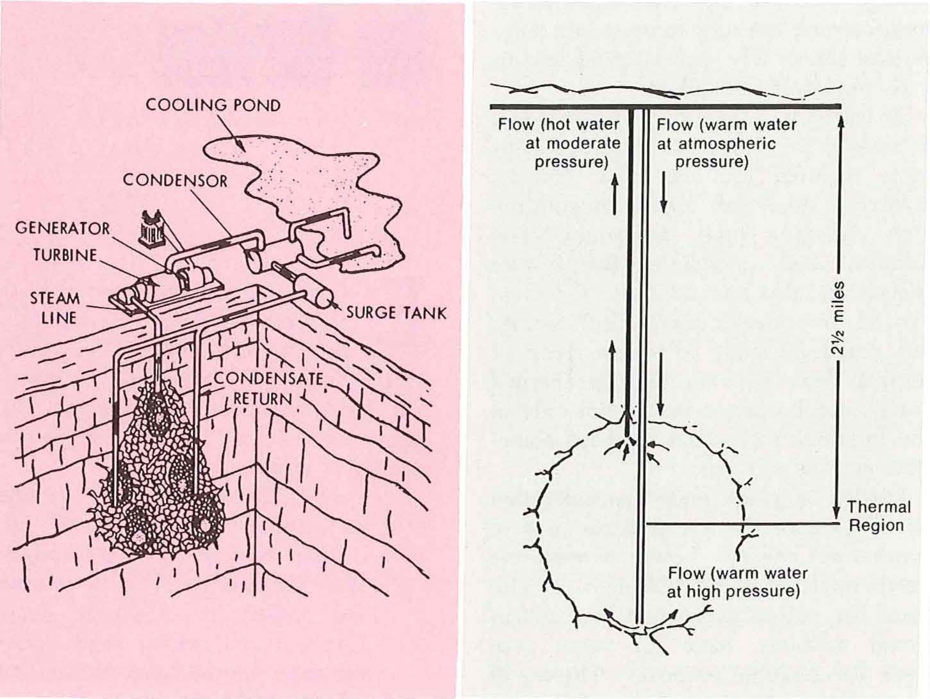
and in some cases, pumping back in—hot, corrosive, pressurized fluids.

- Power conversion. Since geothermal energy is generally at lower temperatures than those reached by burning of fossil fuels, advanced technology in power generation is needed. Bigger turbines may suffice in some instances, but prime movers of unconventional design and the availability of improved heat exchangers may be the limiting factors in the design of geothermal powerplants.
- Environmental monitoring. Once the kinds of potential environmental problems can be foreseen, instruments and techniques must be developed for tracking any effects due to production activities.

The geothermal resource, on the threshold, requires research on a number of peripheral issues if it is to be developed in an orderly and timely manner that protects the interests of all concerned.

A host of legal questions require analysis: Who has the right to the geothermal resource in place? What legal and economic problems might arise under the Geothermal Steam Act for development of Federal lands? Are present State regulatory provisions dealing with drilling and development on private lands adequate to protect the public interest and yet without unreasonable inhibition on private development? Are existing laws controlling the environmental impact of geothermal development adequate? Sho Sato of the University of California, Berkeley, is attempting to answer some of these legal and institutional questions for development in the Imperial Valley. The Futures Group of Glastonbury, Connecticut, is conducting a broad technology assessment of geothermal resource development, examining the economic, social, and environmental impact on the United States.

Heat Extraction From Hot Dry Rock



Hot rock energy. A general approach to generating electricity from hot dry rocks is to first drill into the geothermal zone, crack the deep rock to expose more surfaces, pump water into it at high pressure and recover hot water through a separate hole, then use the resulting steam to drive a turbine.

Geothermal energy systems have advantage over many alternative for of energy in that their environmer effects are confined to the immedi vicinity of the facility. In contrast, otl fuel cycles may involve mining, proce ing, transporting, and disposing of sp wastes, with potential impact on environment at great distances from site.

Locally, of course, there is disrupti On the site, noise and air pollution fr hydrogen sulfide, ammonia, and otl vapors may be problems, but th should be controllable. A more seri consideration is related to land sub dence caused by withdrawal of ge thermal fluids. The problem can controlled by limiting withdrawals fr a field to a safe rate and by rechargi the field with injected water, as is do to prevent subsidence in oil fields. R charge may also be desirable to preve contamination of ground and surfa waters by the runoff of waste geothe mal fluids. However, there are sor cases in which recharging increases se mic activity. Guidelines for operati are expected to emerge as more know edge is acquired through research engineering and management of ge thermal reservoirs.

To assess the magnitude of futu subsidence and fault movement, NS has funded the State of California study the natural tectonic movements the Imperial Valley before geotherm development begins on a major scal The Valley was surveyed in the wint of 1973-74 and the data will be con pared with data from a 1971-72 surve thus permitting evaluation of any m tions that occur once geothermal oper tions are under way. This informatic should be useful for predicting enviror mental impacts in other areas in whic geothermal operations are about begin.

Energy from geothermal resourc may, for a number of years, remai small in the overall picture, but on regional basis, it can be more importan According to one estimate, Californi could one day get 20 percent of i energy from geothermal resources. Wit American industry showing increasin interest in the commercial possibilitie and with the Federal programs support ing research, advanced technology deve opments, and experimental generatin facilities, geothermal energy may we make a significant contribution to fillin the Nation's energy needs. ●

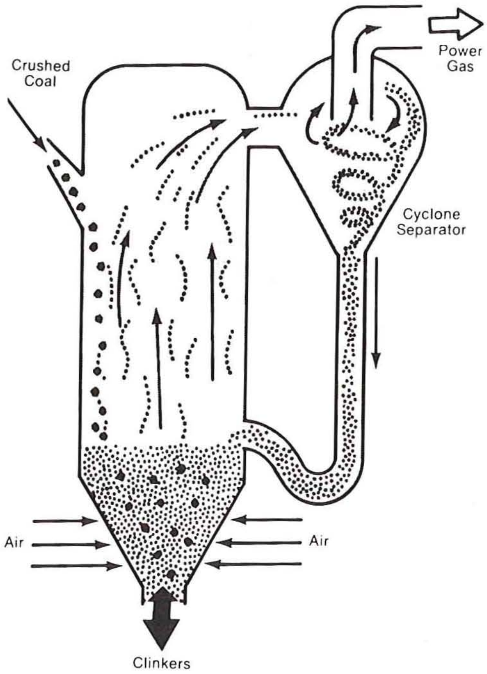
COAL
Gasification

Though people may disagree over exact figures, proportionally the United States has oil and gas reserves for roughly 50 years, and coal for 500. In the era of cheap petroleum, coal fell into disfavor. Now, as we begin to detect the bottom of the oil barrel, coal is taking on new luster.

Coal, like petroleum products, can be burned in boilers to produce steam, but it's not as attractive as oil or natural gas, which are easier to handle and cause fewer pollution problems.

But coal doesn't have to be burned to be used. Converting coal to fuel gas is a 19th century technology; many American cities did it routinely until the late 1930's when the synthetic product was driven out of the market by natural gas. In Europe and Africa, to a limited extent, the process is still in commercial use.

The process is to drive off "power gas," a mixture of combustible but low heat-producing carbon monoxide, hydrogen, and nitrogen. Air and steam, driven through a bed of coal heated to about half its normal combustion temperature (about 1,800° F vs. 3,600° F) decompose to react with the carbon to produce the combustible products. The heat value of power gas is about one-sixth that of natural gas, making it uneconomical to transport over substantial distances. It can, however, be burned nearby to produce electricity economically.



Coal gas. Development of this type of reactor could permit production of very large amounts of "power gas"—enough to fuel a 300-megawatt electric generating plant—by combining an upper fast fluidized bed to gasify fine particles of coal and a lower section to gasify large particles and to remove ash-matter or clinkers.

The problem has been how to convert extremely large quantities of coal—thousands of tons per day for a city-sized powerplant—into such gas. At the City College of New York, a team of researchers under Arthur Squires is developing techniques to do so.

There are several problems with presently available gasifiers: They can't process enough coal in one unit, they require coal in lump form, they use large amounts of heat-absorbing water vapor, and they form tars. To overcome some of those problems Squires and his colleagues are using what is called a "fast fluidized bed."

The fast bed, invented by Lothar Reh of the Lurgi Company, uses high gas flows and provides a cyclone for the return of solid particles to the bottom of the bed at a high rate. This high gas flow permits a uniform mixing of gas and heated coals, yielding a more uniform temperature throughout. By using high temperatures they can minimize the production of tars or other undesirable byproducts. Also, the amount of steam required is reduced, and it is converted almost entirely into hydrogen and carbon monoxide. This, of course, increases the system efficiency significantly.

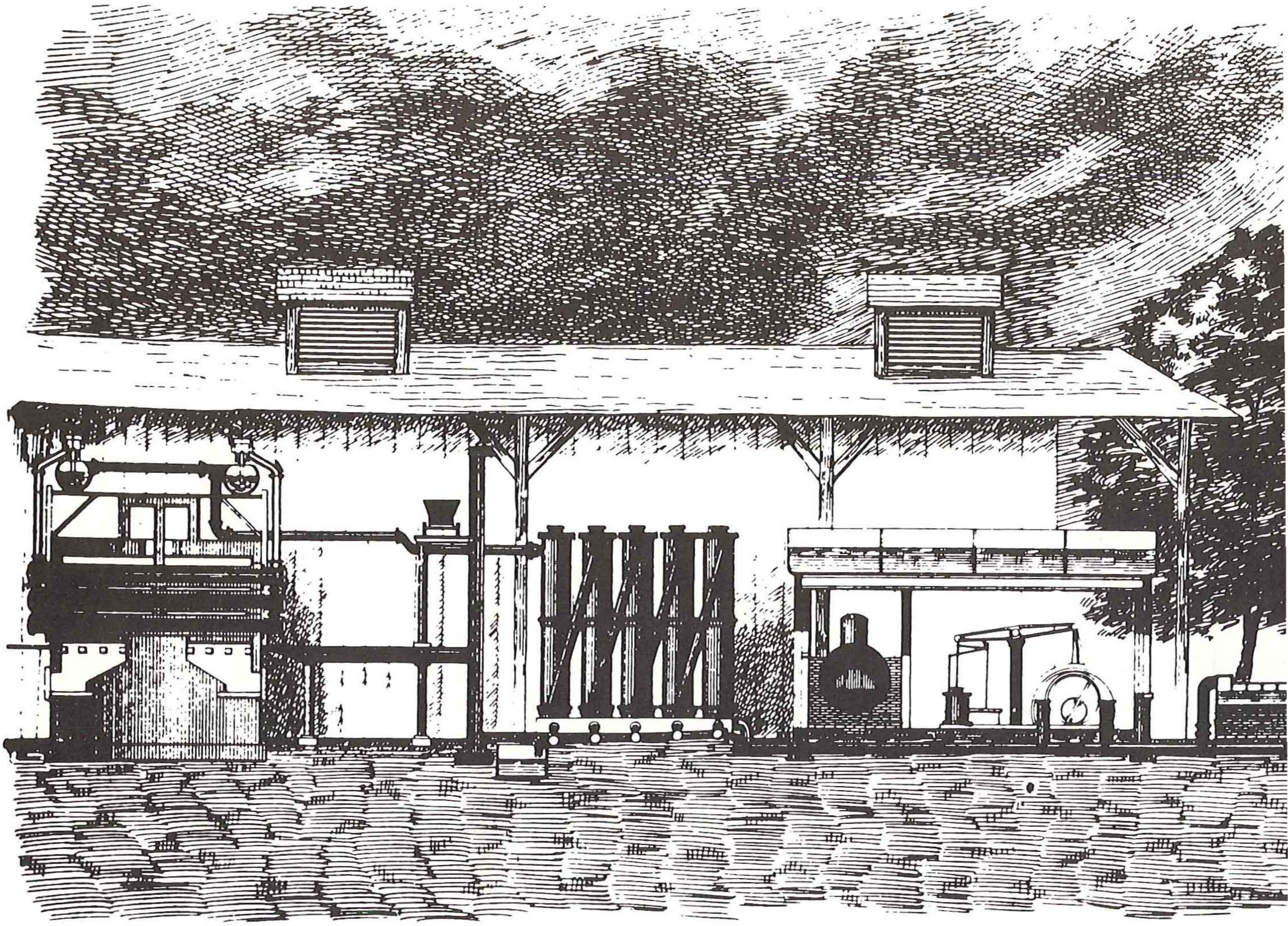
The research team envisions using the technique in a "coalplex," a system in which coal is gasified in the fast fluidized reactor and the resultant power gas burned in a nearby combined-cycle generating plant. (A combined cycle plant employs the exhaust heat from initial burning for a secondary generation of power. See "Generating Electricity: Wasting Less" on page 33.) The team believes that gas and steam turbines together could yield a conversion efficiency of 50 percent with advanced turbines.

If the system is used differently, with the rapid heating of the coal to about 1,500° F in the presence of hydrogen, higher quality gases result: methane for pipeline use; and benzene, toluene, and xylene, constituents of high octane gasoline. Benzene and methane yields up to 40 percent look possible.

The group estimates the system could be brought on-line within a decade on a large scale.

Beyond substitution for the increasingly scarce natural gas and petroleum, the coalplex would reduce pollution problems. Experiments conducted on laboratory-scale instruments have been very encouraging so far in removing both fly ash and sulfur. Sulfur is converted to hydrogen sulfide in the gasifier and scavenged from effluent gases by running them through a calcined dolomite filter, yielding calcium sulfide. The calcined dolomite can be reclaimed with a relatively small power input, producing a commercial sulfur. Nearly all (99.9 percent) of the fly ash could be removed simultaneously by collecting it on such filters.

While firm cost estimates for their systems are not yet available, they are thought generally to be competitive. The major consideration, however, is that if decisions to do so were made now, coalplexes could be generating electricity efficiently within five to ten years. Looking even further into the future, the CCNY team suggests the possibility of an "energy tunnel" leading from a rural coalplex into a city, with energy-intensive industries located above the tunnel to form an "energy corridor." ●



Gasification 100 years ago. Though inefficient by modern criteria, coal gas works like this were widely used in the 19th century.

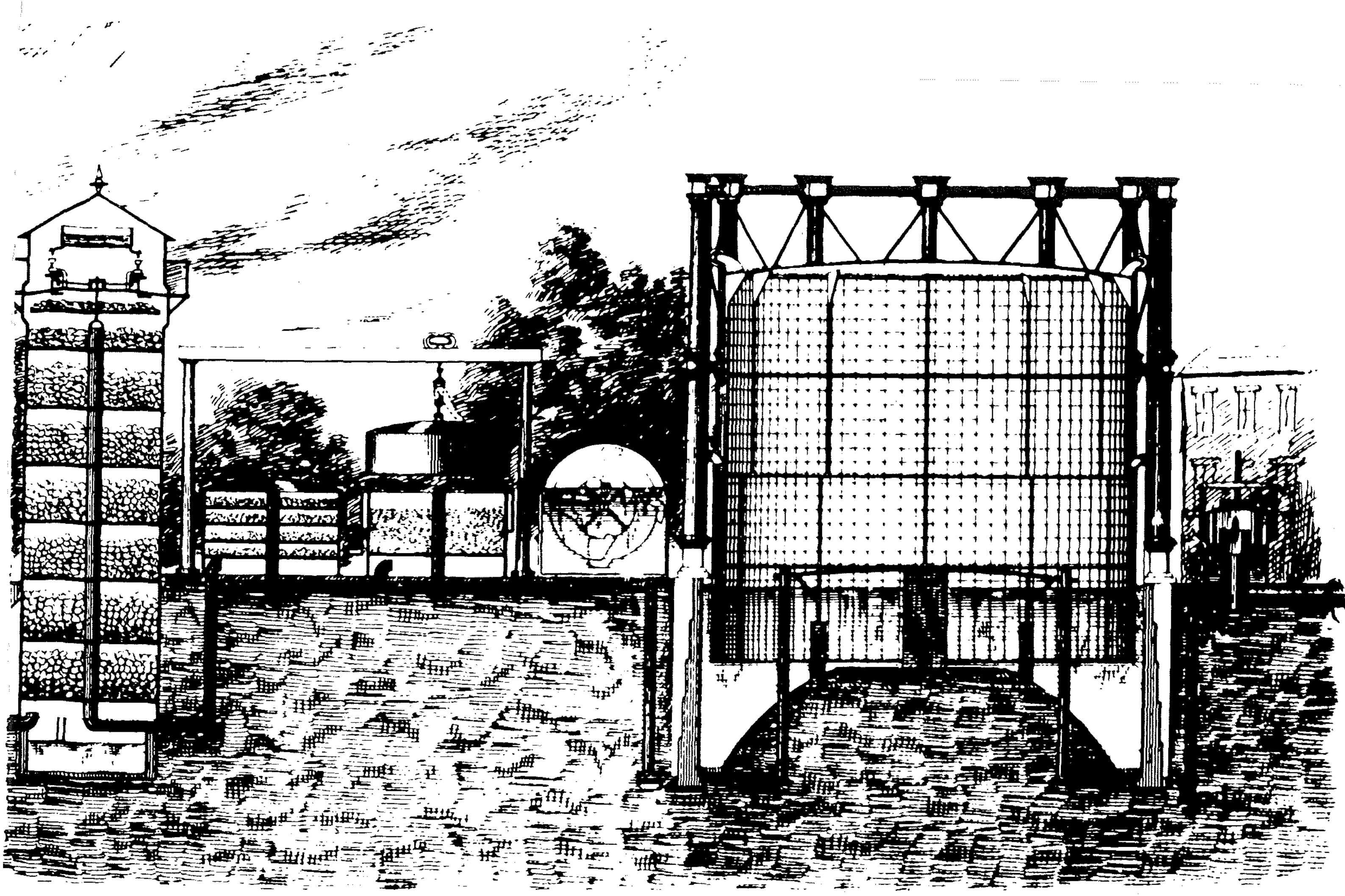
COAL
Liquefaction

During World War II, Germany made gasoline from coal in damn-the-expense style; they had to keep their war machine going. Today, petroleum-poor South Africa keeps a conversion plant going to produce gasoline from its abundant coal supply—another uneconomic program aimed at a national priority: independence from outside energy sources.

But in the United States, for decad
a petroleum exporter, and where gas
line, at least until recently, was cheap
than distilled water, liquefaction of co
has simmered on the back burner. Th
heat has now been turned up in r
sponse to the need for low-sulfur, lo
ash fuel for powerplants.

Liquids in this use have one gre
advantage over gases. They can
manufactured and stockpiled, then di
tributed according to demand. Indee
it is not even necessary that the fin
product of coal liquefaction be liqui
one of the most promising process
goes through a liquid step to produce
clean-burning solid. This solvent-r
fined coal (SRC) process is one of th
half dozen liquefaction schemes no
under intensive development.

In the SRC process coal is mixed wi
a liquid solvent, itself derived from th
coal, then heated and passed (with a
ditional hydrogen) to a high pressu



reactor. Hydrogen and hydrogen sulfide are then separated from the mixture, it is filtered, the solvent is distilled for reuse, and the final product is recovered either as liquid or solid.

Some of the sulfur-containing compounds are removed as hydrogen sulfide. The remaining inorganic sulfur and other extraneous minerals are taken out during filtration. The result is a low-sulfur (0.5 percent), low-ash (0.1 percent) fuel for powerplants.

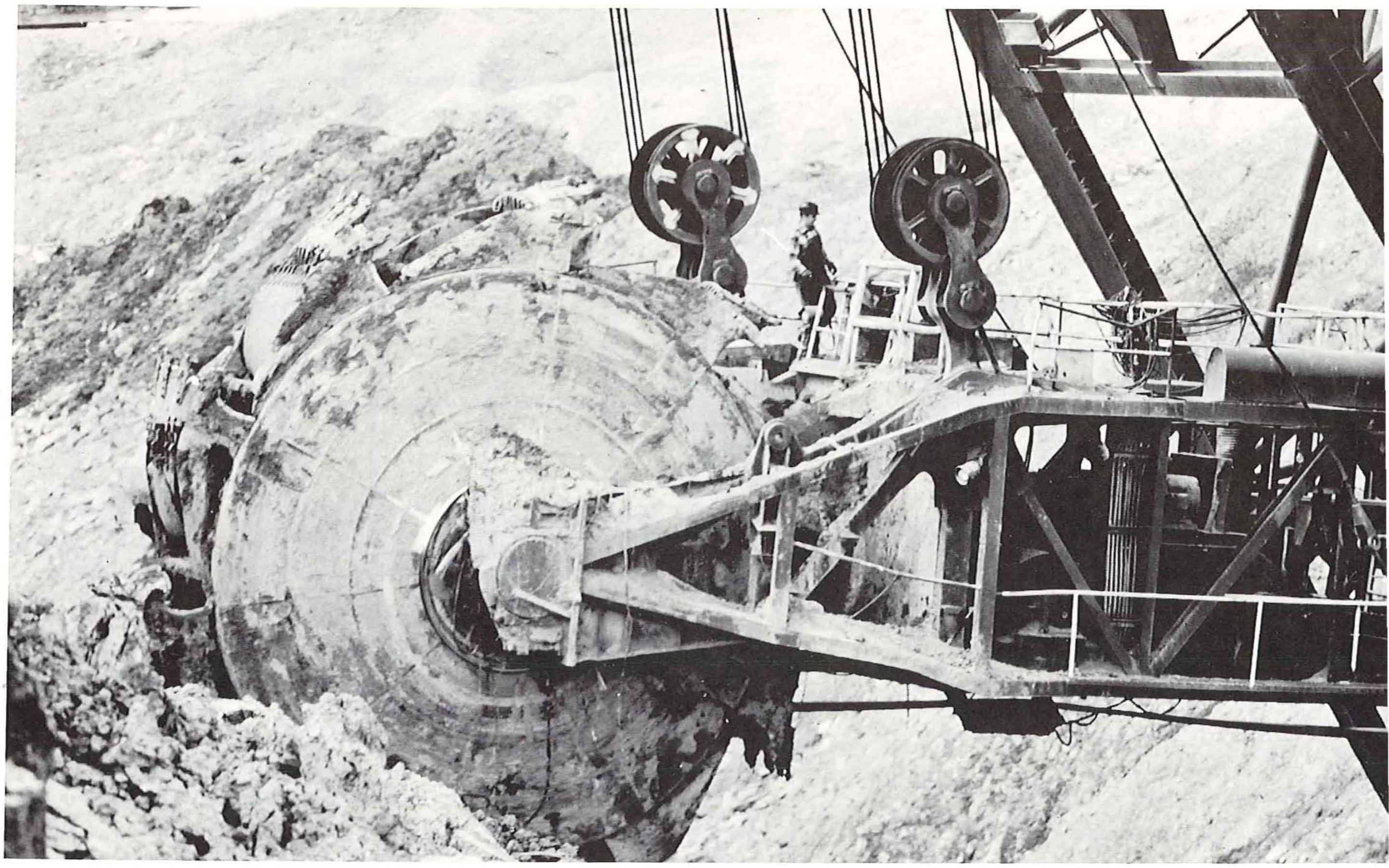
The SRC process is straightforward enough, but there are many points at which it might be made more effective if it were better understood. For example, although the SRC concept is more than a decade old, exactly what is happening as the solvent dissolves the coal is, strictly speaking, a mystery. Nor have the quantitative relationships between the operating variables and the efficiency of the conversion been worked out.

A team at Auburn University under Z. Lowell Taylor is conducting experiments to develop a mathematical model of the SRC process, which could lead to important improvements in the process itself and be of great aid in scaling up the plants. (Two major pilot plants are now being constructed, one of them by Southern Services, Inc., in Wilsonville, Ala., near Auburn. Southern Services, which is helping NSF fund the project, will make its plant available to the Auburn group for tests and scaling up of their work.) The research team will study the fundamental chemistry and physics of the coal's dissolution in the solvent, seeking and attacking the rate-limiting step in the process. They also hope to determine the effect of changes in processing conditions, as well as the characteristics of the coal itself on yields of various products during the dissolution.

Meanwhile, at the University of Kentucky, a group under Richard Kermode has begun studying cost-controlling steps in coal liquefaction. In conjunction with the Ashland Oil Co., and under an NSF grant, the Kentuckians will focus on the supply of process hydrogen, the separation of the ash solids from the coal oil, catalysis in the solvation-hydrogenation approach, and reactor design and char utilization in the pyrolysis approach. Foam flotation for the ash-separation step, for example, appears a promising substitute for filtration.

In all the approaches to liquefaction now under development or research, there is still one very basic difficulty: Coal is not simply coal. There are a large number of coal types known, differing in the relative amounts and kinds of organic components present, in the organic structure, in the amounts and kinds of mineral impurities, and in the trace elements. The most extensive reference collection of coals available for research is at Pennsylvania State University, where Peter Given is leading a research team in studies of how the coal's own characteristics will affect any liquefaction process in terms of gas yield, oil yield, viscosity, and degree of removal of unwanted constituents.

By relating these factors to the original coal, the Given group will be able to point processors towards favorable types of coal and away from types of feedstock that might produce poor yields in a specific process or even contain elements that would "poison" certain catalysts. Such data will be vital to the management of coal reserves, siting of plants, and reduction of costs



Big bite. Much of the United States' plentiful coal resource is most economically recovered by strip mining—exposing underground coal layers by using enormous machines like this to remove the overburden of soil and rock.

The Gulf Research and Development Co., a cooperator in the investigation, has a small prototype commercial reactor in which the group can test different coals. ●

COAL

The Two-Step Fuel Cell

Another ingenious use of coal to produce power (without burning in this case) is in the form of a fuel cell being studied by Stanford Research Institute. Basically, a two-step process would use the carbon of heated coal to convert lead oxide into metallic lead and then reconvert the lead to lead oxide to generate electricity. The electricity results from the release of two electrons in the process.

This two-step process bypasses attempts to produce electricity directly by oxidizing the fuel, a process described by SRI as "cripplingly difficult even with 'clean' gaseous fossil fuels."

Two cells are involved. In the first, powdered coal is fed into a molten carbonate/powdered lead oxide medium at 1,100° F. The coal interacts with carbon dioxide to produce carbon monoxide, which reduces the lead. The rate at which this takes place was found to be dependent mainly on the CO_2 available, which in turn is a function of the rate of coal used.

The second step is the oxidation of lead by the carbonate. The lead is recycled; the only product consumed is coal. Initial experiments show that ten kilowatts could be generated per hour in a one-cubic-foot-volume reaction chamber. With coal costs of about $10 per ton, the system would produce power at a cost of about 34¢ per kilowatt-hour.

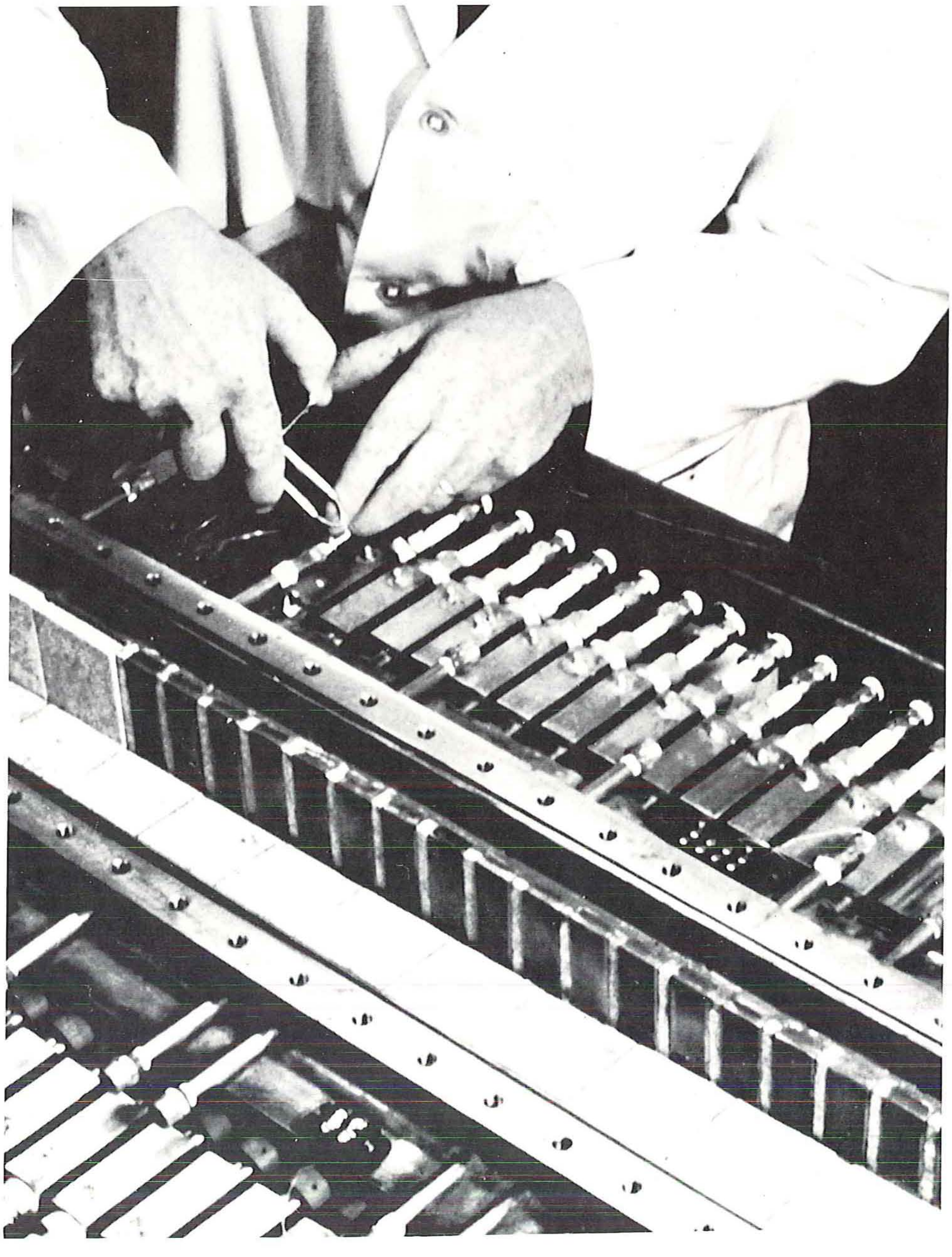
The experimenters are quick to poi out that the system is far from practic use; only initial reaction studies ha been made to date. But it has potenti beyond its simplicity and reliability. S far, they report, they have used s different grades of combustible carbo obtaining excellent results with eac Moreover, it is nonpolluting: The sulf in the coal is highly reactive with th alkali carbonate of the molten mediur which can be de-sulfurized and reuse With the coal ash and sulfur remove in the process, the only effluents to th environment are water and some carbo dioxide.

SRI feasibility studies suggest th increasing flow rates of coal in th same one-cubic-foot cell could increas output to a conservative 60 kilowatt The electrochemical industry (aluminu or magnesium plants, for example would be a prime prospect for the cel It could use the cell's direct current, an the industry is experienced with molte salt technology. Significantly, the electrochemical industry uses ten percent o the Nation's power output. A secon substantial potential use would be fo on-site, small capacity (10-100 kilowatt power generation, normally provided b internal combustion engines. ●

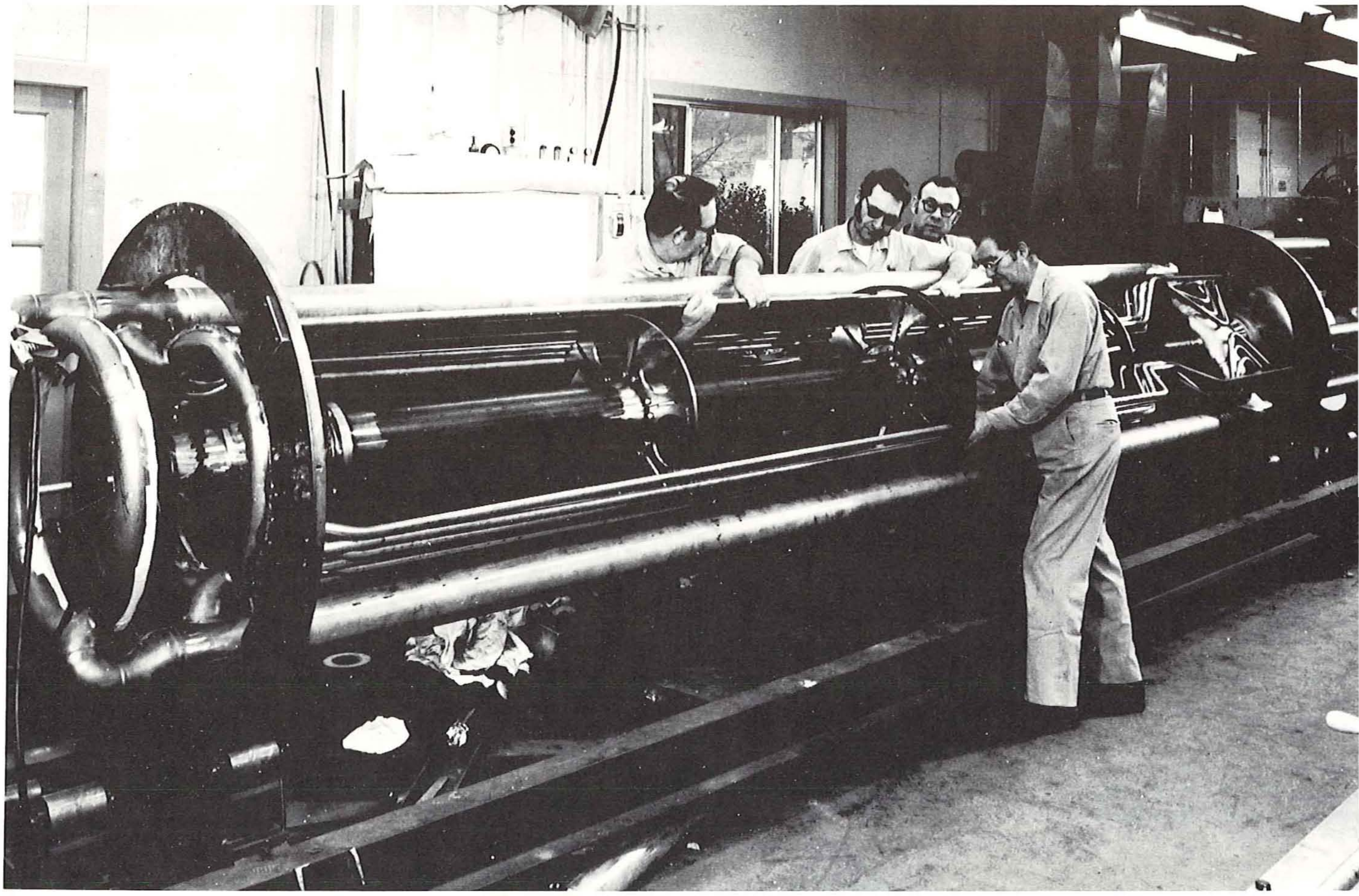
UTILIZATION OF ENERGY

Generating Electricity: Wasting Less

There are two distinct kinds of energy conservation. One, consuming less energy by combinations of social and political actions (lowering thermostats, carpooling, etc.), was discussed in "Energy Systems/Conservation" on page 6. A second kind of conservation is primarily technological—the reduction of waste in the "handling" of energy. In 1971 the United States consumed about 64 Quads (quadrillion Btu's) of coal, oil, gas, nuclear, and hydroelectric energy. An astounding 50 percent of that energy, about 32 Quads, was wasted, given off as useless heat to the environment. With waste of that magnitude, even slight increases in efficiency offer great benefits.



No moving parts. This laboratory device is being used in research on magnetohydrodynamics, an electricity-generating technique in which plasma passes through a strong magnetic field to generate power. Coupled with turbine generators, MHD generators could boost conversion efficency beyond 50 percent.



Better than water. This experimental potassium boiler takes advantage of the higher operating temperatures—and higher thermodynamic efficiency—possible with metallic vapors at about 1,500° F instead of water vapor at 1,000° F. Waste heat from the potassium cycle is then used in a conventional steam cycle.

Some 93 percent of the Nation's electricity is generated by conventional steam-driven powerplants, in which a fuel-heated boiler produces steam, which flows over the blades of a turbine, rotating a conductor through a magnetic field, and producing power. Since 1900, the efficiency of these has risen from about 5 percent to about 35 percent, generally by increasing the inlet temperature of the steam—from about 500° F to a "super heated" 1,000° F or so. Since 1950 no substantial further improvements have been made.

The maximum efficiency of a heat-driven engine was figured out back in 1824 by Nicholas Carnot. The greater the temperature difference between heat in and heat out, the greater the system efficiency. Increasing the efficiency beyond 35 percent—by raising the steam temperatures beyond 1,000° F or by widening temperature differences—is very difficult. Steam expands tremendously at high vapor pressures, requiring relatively large piping. Above 1,100° F, steam tends to dissociate into oxygen and hydrogen; the hydrogen leaks through metal walls, and the oxygen corrodes and drastically reduces system life. Further, water requires a relatively high input to raise its temperature.

A more attractiye way to improve system efficiencies is by taking advantage of liquid metal technology, or by adding turbines at the high temperature end ("topping") or the low temperature end ("bottoming"), taking advantage of the waste heat. A. P. Fraas and his associates at Oak Ridge National Laboratory have proposed using potassium vapor for a topping cycle in a sealed Rankine system (one in which the working fluid is recirculated). They propose further to employ a fluidized bed coal-burning system in which crushed limestone or dolomite would remove the potentially polluting sulfur compounds. The system, operating in conjunction with a steam turbine cycle, is calculated to increase thermal efficiency to 50 percent. Not only would a fuel savings
of some 25 percent result, but pollut
waste heat would be cut in half.

Potassium vapor, being an elemen
and not a molecular compound, rema
intact and would permit higher i
turbine temperatures—1,500° F. Its c
rosive qualities are such that tube
can be expected to be ten years or mo
Further, as the power industry incre
ingly builds nuclear plants, the indus
is becoming familiar with potassi
vapor technology.

The Oak Ridge group has now co
pleted design and fabricated parts fo
potassium boiler-furnace module. In c
cept this device would expand vapor
1,540° F from the potassium boi
through a turbine and condense it
1,100° F. The heat rejected from
potassium cycle is used to produce ste
at 1,000° F to 1,050° F for the ste
turbine cycle.

An approach using existing techno
gies, coupling a diesel engine—not
among reciprocating engines for its hi
efficiency (35-40 percent)—with a b
toming cycle, is under study by Ther
Electron Corp., working with two engi
manufacturers, Caterpillar and Fa
banks-Morse. This project will exami
the feasibility of using diesel reject he

and an "organic fluid" Rankine cycle to improve system efficiencies up to 50 percent.

An exotic alternative to boiler systems is the magnetohydrodynamic (MHD) generator. MHD generators burn fuels at high temperatures (4,800° F); when an easily ionizable "seed" material is injected, ionized gas, or plasma, is produced. This electrically charged mass of ions, propelled by its own thermal expansion, moves through a magnetic field producing, without rotating machinery, electric power. Theoretically, such systems, with topping (and bottoming) cycles, could yield an efficiency of about 55 percent, half derived from the MHD current directly and half from high-temperature gas turbines.

Beyond the benefit of higher efficiency, MHD generators are expected to reduce chemical pollution. Seed particles (predominantly potassium carbonate) injected during combustion react with sulfur in the fuel to form an easily removed precipitate (K_2SO_4). The problem of nitrogen oxides, anticipated originally because of the high operating temperatures, fades to an acceptable level if initial burning is choked and excess air is added downstream. The major exhaust products then are water, nitrogen, and carbon dioxide—all of which are naturally present in the air.

There are difficulties, however. A key one concerns the life of components; the high temperatures (4,000° F) of the effluent products from the MHD generator tend to advance corrosion. Another is that to attain an overall output efficiency of 55 percent, the plasma, with its relatively weak conducting properties, must be passed through an extremely strong magnetic field.

The magnetic fields, about 80,000 gauss, will be produced by superconducting magnets operating at temperatures near absolute zero. A group at Stanford University will be examining the influence of high fields on plasma stability, on boundary layers (influences near the chamber wall), and on heat transfer. The results will be invaluable to engineers who would build such equipment. Although MHD has been worked on here and there for a dozen years; it is only recently that considerable effort is going into it. The United States is now working cooperatively with the Soviet Union, which has a large natural gas-fueled system in the start-up (to 8 megawatts so far) stage now. ●

UTILIZATION OF ENERGY

Storing Energy: Smoothing Out the Demand

Storage of energy is probably the key obstacle to be overcome in the full development of solar energy, and its limitations and some ways to get around them were discussed in "Storage: Making H While the Sun Shines" on page 23. But storage is also a problem in more conventional power systems.

Large powerplants operate most efficiently at or near their peak output. At present, however, there is no feasible way usable over the whole country to store large amounts of electrical energy. (A few plants, near large water systems, can use electricity generated in slack periods to pump water to a higher elevation, then let the water drive turbines for hydroelectric power when demand peaks.) One result is that present U.S. generating capacity is nearly twice that required for the Nation's overall average power requirements, and much of the power generating equipment is often used below peak efficiency.

Even where hydroelectric storage can be used, losses run about 35 percent, which means the fuel originally burned is about 75 percent wasted. But on the horizon may be a welcome development. A superconducting magnet, because of its lack of electrical resistance, should be able to retain about 92 percent of the energy put into it for storage. If sufficiently large magnets could be developed (on the order of 1,000 to 10,000-megawatt-hour capacity—which is about the output of one large modern powerplant for one to ten hours), the need for new generating plants would be cut drastically. For a 10,000-megawatt-hour system, a magnetic coil with an outsic diameter of some 300 meters buried the ground with field strength of 100,00 gauss would be required. The cost, sti not clearly determined, might be accep ably low. Roger Boom and his colleagu at the University of Wisconsin are stud ing the technical and economic facto involved in designing such a system.

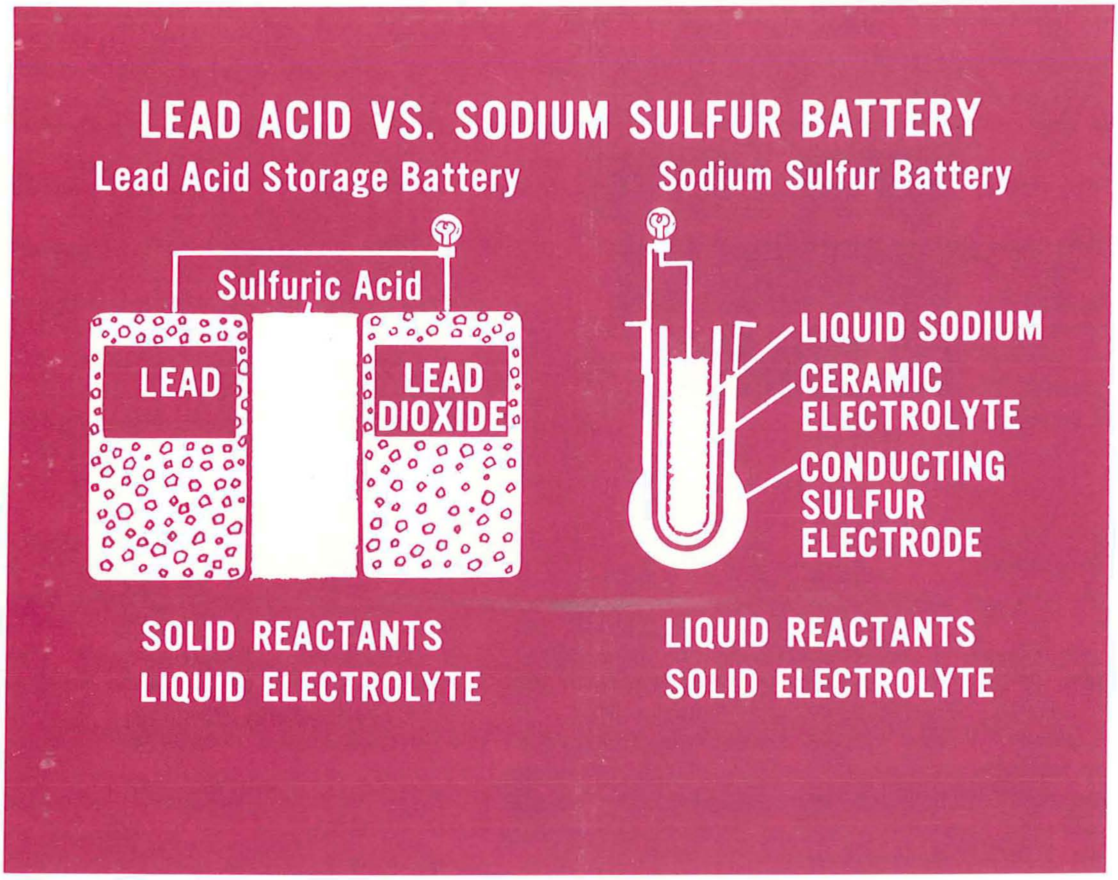
There is, of course, one well-know way to store small amounts of ele tricity—the battery. Better batteri would offer many energy conservin possibilities by absorbing excess ele trical power at off-hours for later us And, perhaps foremost, they offer th possibility of a gasoline-less automobil

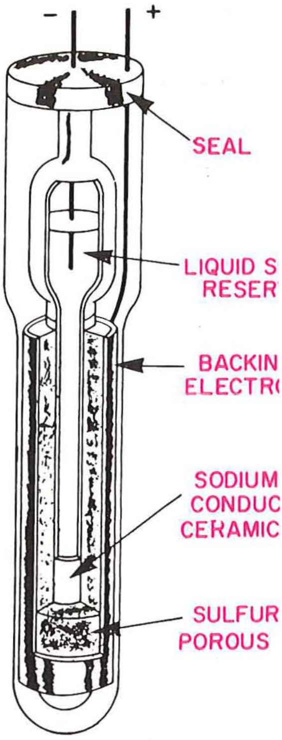
A key project, funded by NSF on cost-sharing basis, is an 11-year-old research program by Ford Motor Compan on a lighter, cheaper, stronger, and mor powerful battery. Achieving this coul make the electric automobile again reality. Ford's effort, with cooperatio from Rensselaer Polytechnic Institut and Utah State University, is directe toward a molten sodium-sulfur batter with liquid electrodes and a solid ele trolyte, just the opposite of a typica lead-acid battery. In it, electrons ar given up by sodium atoms to the external circuit; the resulting sodium ion migrate through the ceramic electrolyt and react with the sulfur to form ion of sodium and sulfur. The ions collec the electrons from the external circuit Since the electrodes are liquid, there i little or no deterioration as in conventional batteries; the reaction is full reversible, resulting in long life, and th energy per pound of the sodium-sulfu battery is projected to be ten times tha of lead-acid.

The total stored energy (which determines the vehicle's range) depends o the weight of sulfur and sodium. Th power density (and thus the vehicl acceleration) depends on the area of th ceramic electrolyte. Ford is aiming at a energy density of 100 watt-hours pe pound, a power density of 100 watts pe pound, a five-year life, and cost of $ to $3 per pound.

The battery would be hot, operatin at a temperature above 575° F; it woul have to be heated when off, cooled whe in operation. One of the problems unde study is how best to contain the hot corrosive materials. Ford is also attempting to understand better and t optimize the properties of the ceramic

The chief energy benefit in using th battery for cars would be the substitution of electricity for gasoline, resulting in cars that run, in a sense, on coal or nuclear energy. Utility companies are also interested in batteries as a practical method of storing large amounts of off-peak power. Thus, successful development of such a battery would help substantially to lessen our dependence on petroleum. ●





Sodium-sulfur cell. A new kind of storage battery under study, with liquid electrodes and a solid electrolyte, would have high power density and low charge-recharge deterioration.

UTILIZATION OF ENERGY

Miles to the Gallon

First cars got bigger and more powerful, and notwithstanding technological advances, transportation efficiency declined. But fuel was plentiful and large gasoline tanks overcame the inconvenience. Then we found that burning so much gasoline caused air pollution, so we added pollution control equipment to our cars and saw transportation efficiency drop further. All along we were able to trade gasoline for convenience. Until now.

Because automobiles are both technological and social devices, there are many kinds of adjustments possible when fuel shortages occur. We can increase the efficiency with which we use cars by carpooling, for example. A possible course is to shift to smaller, lighter vehicles. And drawing on the potentials of technology, we should be able to increase the engine's efficiency as well as the car's. Right now many engines are perhaps 15-percent efficient. NSF recently began a research program, aimed at understanding basic fuel combustion and conversion processes, to change that. A successful research effort could, by 1985, increase eng efficiency to as high as 50 percent. A along with an increase in energy c version efficiency, there would be l waste heat—and perhaps fewer pol tants—released to the atmosphere.

To understand combustion in engine—whether the fuel is gasoline some future exotic like alcohol— must fill the gap in knowledge betw the microscopic properties of matter a the large-scale behavior of the comb tion system. So researchers will be loo ing at staged combustion and die combustion characteristics, particle a droplet dynamics, fuel injection and co trol systems—all leading to definition a basic combustion model. The resear program will also be drawing on a augmenting studies done in other are to provide the kinds of high tempe ture/low friction materials that advanc automotive engines may require. ●

Better combustion. Big car or small, all have very low efficiency because so muc of the gasoline's energy is lost as waste heat. With so much energy going into car transportation, improvements in fuel combustion efficiency offer great potenti for energy savings.